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Request for grant of a patent

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1. Your reference
2636202/DS

2. Patent Application Number **0019082.7** -3 AUG 2000

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

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Patents ADP number *(if known)* 36301008

If the applicant is a corporate body, give the country/state of its incorporation

Country: JAPAN
State:

4. Title of the invention

METHOD AND APPARATUS FOR GENERATING MODEL DATA FROM CAMERA IMAGES

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Patents ADP number 1826001

6. Priority details

Country	Priority application number	Date of filing

Patents Form 1/77

7. If this application is divided or otherwise derived from an earlier UK application give details

Number of earlier application   Date of filing

8. Is a statement of inventorship and or right to grant of a patent required in support of this request?

YES

9. Enter the number of sheets for any of the following items you are filing with this form.

Continuation sheets of this form	0
Description	65
Claim(s)	27
Abstract	2
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10. If you are also filing any of the following, state how many against each item.

Priority documents	0
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Statement of inventorship and right to grant of a patent *(Patents form 7/77)*	1 + 3 copies
Request for preliminary examination and search *(Patents Form 9/77)*	0
Request for Substantive Examination *(Patents Form 10/77)*	0
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11. I/We request the grant of a patent on the basis of this application

Signature Beresford & Co   Date 3 August 2000

BERESFORD & Co

12. Name and daytime telephone number of person to contact in the United Kingdom

David SPROSTON

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Statement of inventorship and of right to grant of a patent

The Patent Office
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Newport
Gwent NP9 1RH

1. Your reference
2636202/DS

2. Patent Application Number
accompanying application reference 2636202

0019082.7 -3 AUG 2000

3. Full name of the or each applicant
Canon Kabushiki Kaisha

4. Title of the invention
METHOD AND APPARATUS FOR GENERATING MODEL DATA FROM CAMERA IMAGES

5. State how the applicant(s) derived the right from the inventor(s) to be granted a patent
By virtue of the employment of the inventors by Canon Research Europe Ltd, and by virtue of an agreement between Canon Research Europe Ltd and Canon Kabushiki Kaisha dated 1 January 1994.

6. How many, if any additional Patents Forms 7/77 are attached to this form?
None

7. I/We believe that the person(s) named over the page (and on any extra copies of this form) is/are the inventor(s) of the invention which the above patent application relates to.

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Patents Form 7/77

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METHOD AND APPARATUS FOR GENERATING MODEL DATA FROM CAMERA IMAGES

The present invention relates to an apparatus and method of operation thereof for generating model data of a model in a three-dimensional space from image data representative of a set of camera images of an object.

It is known to create three-dimensional computer models of real objects based on the input of image data in the form of a series of image frames which may be derived from a series of photographs taken from different camera positions or from a video recording taken from a moving camera.

Having generated a set of model data, a model image is displayed and may be compared with camera images of the object from which the existing model data has been derived.

A first aspect of the present invention relates to refinement of the existing model data by allowing a user to identify an additional feature in one of the camera images, this feature being absent from the displayed model image, and which the user wishes to include in the model by the input of additional model data.

One method of refining the model in this respect requires the user to continue the process of entering matching points identified in successive image frames and the apparatus to then process the matching point data by re-running the model program to incorporate an expanded set of data. This process however requires a substantial amount of computer processing effort with consequent delay. In some instances, the additional feature may only be visible in a single frame, making it impossible to identify a matching point in a second frame.

The present invention seeks to provide an improved method and apparatus allowing an additional feature to be added as a result of user input based on a single frame.

According to the present invention there is disclosed a method of operating an apparatus for generating model data representative of a model in a three dimensional space from image data representative of a set of camera images of an object;

the apparatus performing the steps of;

displaying a model image based on an existing set of model data;

displaying one of the camera images of the object for selection by a user of an additional feature to be represented by additional model data;

receiving an image point selection signal responsive

to user actuation of an input means and identifying co-ordinates of an image point in the camera image defining the selected additional feature;

calculating a locus in the three dimensional space defining positions of possible model points corresponding to the image point and consistent with the geometric relationship between the object and a camera position from which the displayed camera image was taken;

displaying a position indicator in the model image at co-ordinates in the model image corresponding to one of the possible model points on the locus;

receiving positioning signals responsive to user actuation of the input means and updating the co-ordinates of the position indicator such that movement of the position indicator is constrained to follow a trajectory in the model image corresponding to the locus;

receiving a model point selecting signal responsive to user actuation of the input means and determining selected co-ordinates of the position indicator to be the position indicator co-ordinates at the time of receiving the model point selecting signal; and

determining co-ordinates of the additional model point in the three dimensional space corresponding to the selected co-ordinates of the position indicator.

In a preferred embodiment, the locus is a straight line in the three-dimensional model space, the straight line

being displayed in the model image as a visual aid to the user in editing the position of the new model point. After finalising the position of the new model point, a model generating process is initiated to incorporate the additional model point into the model data and to generate surface elements of the model, allowing the new model image to be displayed including the surface elements for comparison with the camera image.

A second aspect of the present invention relates to the manner in which the model data is edited when a new model point is added to the existing set of model data, either using the above disclosed method or by other methods. Incorporation of an additional model point generally requires the surface elements of the existing model to be modified, at least one of the surface elements being replaced by a plurality of new elements which include the new model point. This aspect of the invention addresses the problem of selecting the surface element to be modified or replaced in a manner which is simple for the user to implement.

According to the second aspect of the present invention there is disclosed a method of operating an apparatus for generating model data defining a model in a three dimensional space, the model data comprising co-ordinates defining model points and surface elements generated with

reference to the model points; the method comprising editing an existing set of model data by the steps of;

adding a new model point to the existing set of model data;

projecting the new model point onto the model and identifying a selected one of the surface elements onto which the new model point is projected;

identifying a subset of the model points which define the generation of the selected surface element;

adding the new model point to the subset to form an edited subset of model points; and

generating one or more edited surface elements from the edited subset of model points to replace the selected surface element.

The identification of the surface element to be replaced is thereby automatically implemented by the apparatus, by operating a computer program selected by the user.

In a preferred embodiment, the projection of the new model point onto the model is processed by defining a centre of projection corresponding to one of the camera positions from which frames of the camera image data were obtained. An interface allowing the user to select an appropriate camera position may comprise a display of a pictorial representation showing the relative positions of the object and the cameras, the camera positions being

represented by icons which may be selected by clicking a computer mouse or other input device.

A further embodiment provides an alternative interface in which thumbnail images of the camera image frames are presented to the user, each thumbnail image constituting an icon allowing selection using a pointing device such as a computer mouse in conjunction with a moveable cursor on the display screen.

A third aspect of the present invention relates to the need to enable the user to evaluate the quality of a model in order to judge whether further refinement of the model data is required and to judge whether any editing procedure has been correctly effected or requires further editing.

This aspect of the invention seeks to provide the user with an interface allowing the user to view a model image for comparison with a camera image, it being advantageous to present the user with compatible views for ease of comparison. The selection of the appropriate model image for comparison with a specific camera image may be time consuming and complex to the user.

According to the present invention there is disclosed a method of operating an apparatus for generating model

data representative of a three dimensional model of an object from input signals representative of a set of camera images of the object taken from a plurality of camera positions, the method comprising;

displaying a set of icons, each being associated with a respective one of the camera images of the object;

receiving a selection signal responsive to user actuation of an input means whereby the selection signal identifies a selected one of the icons;

determining a selected camera image from the set of camera images corresponding to the selected icon;

displaying the selected image;

determining position data representative of a selected camera position from which the selected image was taken;

generating in accordance with said model a model image representative of a view of the model from a viewpoint corresponding to the position data; and

displaying the model image for visual comparison with the selected image by the user.

This method therefore allows the user to simply select a camera image using a set of icons and provides automatic processing using a computer program to generate a model image representative of a view of the model from a viewpoint corresponding to position data determined when the user selects a particular icon.

The icons may be representations of camera positions relative to a representation of the object being modelled or alternatively the icons may be thumbnail images of the frames of camera image data.

The user is thereby presented with a computer interface allowing correctly comparable model and camera images to be rapidly selected for evaluation. The selection process may thereby be repeated to view the images from different viewpoints in order to rapidly gain an overview of the quality of the model data as a basis for deciding whether further editing is required.

Embodiments of the above aspects of the present invention will now be described by example only and with reference to the accompanying drawings of which;

Figure 1 is a schematic representation of components of a modular system in which the present invention may be embodied;

Figure 2 is a schematic representation of a model window;

Figure 3 is a schematic representation of a camera image window in which a displayed camera image includes an additional feature which is not represented in the model image of Figure 2;

Figure 4 is a schematic representation of a calculated locus in the 3-D model space for a new model point;

Figure 5 is a schematic representation of a model window including a new point moved by the user to positions constrained by the calculated locus;

Figure 6 is a schematic representation of a model window during user selection of points for connection to the new model point;

Figure 7 is a schematic representation of the model window in which the displayed model image shows the new model point and facets;

Figure 8 is a schematic representation of the model window showing the model image including the added model data, viewed from the same direction as the camera image of Figure 3;

Figure 9 is a schematic flowchart showing the method steps for adding the new model data;

Figure 10 is a further general illustration of the apparatus including a display screen;

Figure 11 is a representation of a model window including

a display of a line representing the calculated trajectory;

Figure 12 is a schematic representation of the addition of a new model point to an existing model according to a second aspect of the present invention;

Figure 13A is a schematic representation of a camera selection window using camera icons;

Figure 13B illustrates an alternative camera selection window using thumbnail icons;

Figure 14 is a diagram illustrating the calculation of a ray intersecting a facet of the model;

Figure 15 is a diagram illustrating the subdivision of a facet to include the added model point;

Figure 16 is a diagram illustrating the display of a new model including the added point and new facets;

Figure 17 is a flowchart illustrating the method described with reference to Figures 12 to 16;

Figure 18 is a flowchart illustrating the step of replacing the existing facets with new facets using re-

triangulation;

Figure 19 is a diagram illustrating the identification of co-ordinates in a camera image of a feature corresponding to the added model point;

Figure 20 is a diagram illustrating the calculation of the intersection with the facet of a ray through the camera image point and the added model point;

Figure 21 is a flowchart illustrating the method described with reference to Figures 18 to 20;

Figures 22 to 26 illustrate a third aspect of the present invention, Figure 22 illustrating schematically camera positions in relation to an object to be modelled;

Figure 23 illustrates a display screen of a computer interface allowing viewpoints to be selected by a user for selecting both camera image and model image;

Figure 24 is a flowchart illustrating the method of implementing the interface of Figure 23;

Figure 25 illustrates an alternative interface display allowing image selection using camera position icons; and

Figure 26 is a flowchart illustrating the operation of the interface of Figure 25.

Figure 1 schematically shows the components of a modular system in which the present invention may be embodied.

These components can be effected as processor-implemented instructions, hardware or a combination thereof.

Referring to Figure 1, the components are arranged to process data defining images (still or moving) of one or more objects in order to generate data defining a three-dimensional computer model of the object(s).

The input image data may be received in a variety of ways, such as directly from one or more digital cameras, via a storage device such as a disk or CD ROM, by digitisation of photographs using a scanner, or by downloading image data from a database, for example via a datalink such as the Internet, etc.

The generated 3D model data may be used to: display an image of the object(s) from a desired viewing position; control manufacturing equipment to manufacture a model of the object(s), for example by controlling cutting apparatus to cut material to the appropriate dimensions; perform processing to recognise the object(s), for

example by comparing it to data stored in a database; carry out processing to measure the object(s), for example by taking absolute measurements to record the size of the object(s), or by comparing the model with models of the object(s) previously generated to determine changes therebetween; carry out processing so as to control a robot to navigate around the object(s); store information in a geographic information system (GIS) or other topographic database; or transmit the object data representing the model to a remote processing device for any such processing, either on a storage device or as a signal (for example, the data may be transmitted in virtual reality modelling language (VRML) format over the Internet, enabling it to be processed by a WWW browser); etc.

The feature detection and matching module 2 is arranged to receive image data recorded by a still camera from different positions relative to the object(s) (the different positions being achieved by moving the camera and/or the object(s)). The received data is then processed in order to match features within the different images (that is, to identify points in the images which correspond to the same physical point on the object(s)).

The feature detection and tracking module 4 is arranged to receive image data recorded by a video camera as the

relative positions of the camera and object(s) are changed (by moving the video camera and/or the object(s)). As in the feature detection and matching module 2, the feature detection and tracking module 4 detects features, such as corners, in the images. However, the feature detection and tracking module 4 then tracks the detected features between frames of image data in order to determine the positions of the features in other images.

The camera position calculation module 6 is arranged to use the features matched across images by the feature detection and matching module 2 or the feature detection and tracking module 4 to calculate the transformation between the camera positions at which the images were recorded and hence determine the orientation and position of the camera focal plane when each image was recorded.

The feature detection and matching module 2 and the camera position calculation module 6 may be arranged to perform processing in an iterative manner. That is, using camera positions and orientations calculated by the camera position calculation module 6, the feature detection and matching module 2 may detect and match further features in the images using epipolar geometry in a conventional manner, and the further matched features may then be used by the camera position calculation

module 6 to recalculate the camera positions and orientations.

If the positions at which the images were recorded are already known, then, as indicated by arrow 8 in Figure 1, the image data need not be processed by the feature detection and matching module 2, the feature detection and tracking module 4, or the camera position calculation module 6. For example, the images may be recorded by mounting a number of cameras on a calibrated rig arranged to hold the cameras in known positions relative to the object(s).

Alternatively, it is possible to determine the positions of a plurality of cameras relative to the object(s) by adding calibration markers to the object(s) and calculating the positions of the cameras from the positions of the calibration markers in images recorded by the cameras. The calibration markers may comprise patterns of light projected onto the object(s). Camera calibration module 10 is therefore provided to receive image data from a plurality of cameras at fixed positions showing the object(s) together with calibration markers, and to process the data to determine the positions of the cameras. A preferred method of calculating the positions of the cameras (and also internal parameters of each camera, such as the focal length etc) is described in

"Calibrating and 3D Modelling with a Multi-Camera System" by Wiles and Davison in 1999 IEEE Workshop on Multi-View Modelling and Analysis of Visual Scenes, ISBN 0769501109.

The 3D object surface generation module 12 is arranged to receive image data showing the object(s) and data defining the positions at which the images were recorded, and to process the data to generate a 3D computer model representing the actual surface(s) of the object(s), such as a polygon mesh model.

The texture data generation module 14 is arranged to generate texture data for rendering onto the surface model produced by the 3D object surface generation module 12. The texture data is generated from the input image data showing the object(s).

Techniques that can be used to perform the processing in the modules shown in Figure 1 are described in EP-A-0898245, EP-A-0901105, pending US applications 09/129077, 09/129079 and 09/129080, the full contents of which are incorporated herein by cross-reference, and also Annex A.

The present invention may be embodied in particular as part of the feature detection and matching module 2 (although it has applicability in other applications, as will be described later).

Figure 10 illustrates generally the apparatus 100 of the present embodiment, comprising a processor 101, display monitor 102, and input devices including a computer mouse 103 and keyboard 104. The mouse 103 enables signals such as an image point selection signal 112 (described below) to be input to the processor.

A disc drive 105 also receives a floppy disc 106 carrying program code and/or image data for use by the processor 101 in implementing the method steps of the present invention.

The display monitor 102 has a display screen 107 which, in the present mode of operation of the program, displays a model window 108 and a camera image window 109.

The processor 101 is connected to a modem 110 enabling program code or image data to be alternatively downloaded via the internet as an electronic signal 111.

The method steps according to a first aspect of the present embodiment are illustrated in Figure 9 in which steps performed by the user and by the apparatus are separated by a broken line 90 representing the interface provided by the display screen 107 and input devices 103,104.

The method begins from a starting point at which the apparatus has already acquired a set of existing model data derived for example using the components in Figure 1 to process input image data in the form of a series of image frames obtained from a camera at respective different camera positions. The model data includes a set of model points and surface elements and estimates of the camera positions in the form of model co-ordinates for camera centres and look-directions derived for example by operation of camera position calculation module 6 to calculate camera positions based on the image data.

At step 91, the apparatus displays in the display screen 107 a model image 20 in the model window 108 as illustrated in Figure 2. Also displayed for side by side comparison is a camera image 30 in the camera image window 109 as illustrated in Figure 3.

The model image 20 of Figure 2 is rendered using existing model data which the user wishes to update in order to add additional model data representing an additional feature 31 which is visible in the camera image of Figure 3 but which has no equivalent in the model image 20 of Figure 2. The model image 20 and camera image 30 as shown in Figures 2 and 3 are generated as views from substantially the same viewing direction.

At step 92, the user views the model image 20 and the camera image 30 and selects an image point 32 in the camera image 30 by using the computer mouse 103 to align a cursor 33 with the selected additional feature 31 and then clicking the mouse to generate an image point selection signal at step 93.

At step 94, the apparatus receives the image point selection signal and processes the signal to identify co-ordinates of the image point in the camera image 30.

Since the camera image 30 is a two-dimensional projection of the object from which the model is derived, the two-dimensional co-ordinates obtained by user selection of the image point 32 do not specify uniquely a position in three dimensions at which the new model point is to be added. At step 95, the apparatus calculates the locus in three dimensions of the positions of possible model points corresponding to the selected image point 32 which are consistent with the geometric relationship between the object and the camera position from which the displayed camera image 30 was taken. This is illustrated in Figure 4 in which the model is viewed from a different viewpoint from that of Figure 2 and in which the locus is a straight line extending in the three dimensional space of the model from the model co-ordinates of the camera centre 40 and through the co-ordinates of the image point

32 in the camera image plane 41.

An exemplary model point 42 lying on the locus 43 is illustrated in Figure 4 at one of the possible positions at which the new model point could be added.

At step 96, the apparatus displays in the model window a new model image 21 as shown in Figure 5 in which a position indicator 50 lies on the locus 43 and is movable in response to movement of the computer mouse by the user so as to be constrained to follow a trajectory 51 corresponding to the locus when projected into the plane of the model image 21. The new model image 21 of Figure 5 is generated as a view of the model from a different viewpoint selected to clearly display the locus. Such different viewpoints are selected by the user by temporarily selecting a different mode of operation from a menu of available modes, the viewpoint selecting mode providing rotation of the model image in latitude and longitude in response to sideways and forward/reverse movement of the mouse respectively.

At step 97, the user views the model image 21 and the position indicator 50 and decides upon an appropriate position of the position indicator 50 to represent the additional feature 31. At step 98, the user actuates the mouse to move the position indicator 50 to the selected

position, the apparatus updating the position of the position indicator appropriately at step 99, and at step 910 the user clicks the mouse, thereby selecting the desired position to set the position of the new model point. At step 911, the apparatus receives a selection input signal corresponding to the mouse click and freezes the position at which the position indicator 50 is displayed in the model image window. At step 912, the apparatus determines the three-dimensional co-ordinates corresponding to the selected position of the additional model point, the co-ordinates being uniquely identified in three-dimensions from the known geometry of the locus and the selected position in the two-dimensional projection forming the model image 21 of Figure 5.

At step 913, the apparatus adds the new model point to the existing model data and at step 914 displays the new model point 64 in the model window 10B together with existing model points, superimposed on the model image 20 as shown in Figure 6.

At step 915, the user views the model image and the new model point and selects a set of existing model points 61, 62 and 63 for combining with the new model point 64 to form a new subset of points to be used in the generation of surface elements of the model. The apparatus then generates the additional surface elements

shown as elements 70 and 71 in Figure 7. Texture data may then be rendered onto the resulting surface model using a texture data generation module 14 as described above with reference to Figure 1.

Figure 8 illustrates the model image incorporating the added model data when viewed from the same direction as the original camera image of Figure 3. In the model image of Figure 8, the additional feature 31 of the camera image 30 is represented by added model feature 80.

The user may decide that the added model feature 80 does not adequately represent the additional feature 31 and, if so, may select an editing mode in which the position of the position indicator 50 may be adjusted and the resulting facetted model reviewed until the added model feature is judged to be correct, this further step requiring the input of further positioning signals and model point selecting signals responsive to user actuation of the mouse.

In an alternative embodiment illustrated in Figure 11, the step 96 of displaying in the model window 108 the new model image 21 together with the indicator 50 may also include displaying a line 120 indicating the path of the trajectory 50.

Alternative embodiments are envisaged in which for example non-linear locus calculation is effected, for example to take account of image distortion known to be present in the camera optics. Alternative means may be utilised for the input of data in place of a computer mouse, alternative forms of pointing device such as touch screen and touch pad devices being usable, or alternatively conventional keyboard devices may be used to input co-ordinates.

In a further alternative embodiment, the step 915 in which the user selects existing model points for surface generation may be replaced by a step carried out by the apparatus to automatically select existing model points to be used in combination with the new model point as a basis for re-facetting the model.

A preferred method of performing such automatic facetting will be described below.

The method of the present invention can be implemented by a computer program operating on the computer apparatus 100, the program comprising processor implementable instructions for controlling the processor 101. The program may be stored in a storage medium such as floppy disk 106. An aspect of the present invention thus provides a storage medium storing processor implementable

instructions for carrying out the above described method.

Further, the computer program may be obtained in electronic form for example by downloading the program code in the form of a signal 111 over a network such as the internet via the modem 38.

Alternative embodiments of the present invention are envisaged in which for example the above described method and apparatus are used to process camera images obtained by selecting frames from a video camera recording, the frames representing different views of the object. The displayed images may additionally be modified to include dimensional information as a guide to the user in determining the optimum position of the new model point.

A further aspect of the present embodiment will now be described, relating to the automatic re-facetting of the model when a new model point is added to a set of existing model points. Corresponding reference numerals to those of preceding figures will be used where appropriate for corresponding elements.

Figure 12 illustrates a new model point 64 which has been added to the data used to derive a model image 20 displayed in a model window 108 in a display screen 107 of a processor controlled apparatus 100 of the type

illustrated in Figure 10 and functioning as a system in the manner described above with reference to Figure 1.

The addition of the new model point 64 may be the result of a process using selection of a camera image point and generating a locus in the model space as described above with reference to Figures 2 to 11 or may be the result of a different process, such as for example the input via a keyboard of numerals representing co-ordinates in the three-dimensional model space.

In Figure 12, the model image 20 is representative of an irregularly shaped object represented schematically by a multi-facetted image in which the surface is comprised of a large number of triangular facets. In practice, the number of facets is likely to be greatly increased beyond the relatively small number illustrated in Figure 12 so that Figure 12 should therefore be regarded as schematic for the purpose of simplicity of representation in this respect.

The method steps required to implement the method are illustrated in the flowchart of Figure 17 in which steps performed by the user are illustrated in the left-hand portion of the flowchart, steps implemented by the apparatus are shown in the right-hand portion of the flowchart and an interface between the user and the

apparatus is represented as a broken line 90. In practice, the interface is comprised of the display screen 107 and the computer mouse 106 allowing the input of pointing signals in conjunction with the display of a cursor 33 on the display screen 107.

The following method steps illustrated in Figure 17 will be described with reference to Figures 12 to 16. At step 170, the user selects via mode icons 230 a mode of operation of the apparatus for choosing a view of the model and the apparatus responds by displaying the model image 20 in the model image window 108. The user actuates the mouse 103 to orient the model view to a position which is judged to be appropriate.

At step 171, the user selects a mode of operation for the addition of model points and the apparatus responds by displaying a prompt for the input of the model point information. The user inputs co-ordinates of the added model point and, at step 172, the apparatus displays the new model point in the model image window 108 as illustrated in Figure 12. The apparatus also displays on the display screen 107 a camera selection window 130 as illustrated in Figure 13A in which the camera positions relative to the object represented by the model image are graphically represented in a manner which enables the user to choose one of the cameras as being appropriately

located for the purpose of defining a centre of projection to allow the new model point 64 to be projected onto the existing model. The user may for example already have knowledge of the object being modelled and a general indication of the required camera view.

In the camera selection window 130, the cameras are represented at their positions relative to a representation of the object 131 by respective camera icons 132 such that the user is able to select one of the cameras by use of the mouse, the user aligning the cursor 33 onto a selected one of the camera icons and clicking the mouse 103 to effect selection.

At step 174, the apparatus receives the camera selecting signal and determines the position of the camera centre 147 in the three-dimensional co-ordinate system of the model.

At step 175, the apparatus calculates the manner in which the new model point 64 is projected onto the surface of the model by calculating a ray in the model space through the position of the camera centre and the co-ordinates of the new model point. As shown in Figure 14, a ray 140 defined in the above manner intersects the surface of the model at a point of intersection 141 which lies within a

facet 142 defined by apices 143, 144 and 145 and also intersects a second facet 146 on exiting the model surface.

At step 176, the apparatus replaces the existing facet 142 with new facets 150, 151 and 152 as illustrated in Figure 15, each of which includes the new model point 64 as a respective apex. At step 177, the apparatus displays the new model image including the added point 64 and the new facets 150, 151 and 152 as illustrated in Figure 16 in which the new facets are highlighted by being cross-hatched (facet 152 is hidden from view).

Step 176 of replacing the existing facet with new facets is illustrated in greater detail in the flowchart of Figure 18. At step 180, the apparatus determines whether the ray 140 intersect one of the model facets. If no intersection occurs, the apparatus displays a prompt to the user to select a model facet at step 181 and at step 182 the user responds by selecting a facet to be replaced, selection being carried out using the mouse and cursor. At step 183, the apparatus determines the set of co-ordinates upon which the selected facet is based and, at step 184, adds the new model point to this set of co-ordinates. In this example, since the facet being replaced is triangular, the set of co-ordinates on which the facet is based consists of three model points. When

the new model point is added, there are four model points as a basis for re-triangulation. At step 185, the apparatus performs re-triangulation to define three triangular facets which connect the set of four points to form part of the surface of the model as illustrated in Figure 15.

If at step 180, the apparatus determines that the ray does in fact intersect a model facet 142 as shown in Figure 14, the point of intersection 141 is determined, thereby defining the facet 142 which is intersected by the ray, and the set of co-ordinates of the intersected facet are then used in combination with the new model point at step 184 to define the set of new co-ordinates. If, as in the case of Figure 14, more than one facet is intersected by the ray 140, the apparatus determines at step 185 which of the facets is closest to the new model point 64 as a subject for re-triangulation. In the example of Figure 14, the facet 142 is therefore selected in preference to facet 146 since it is closer to the new model point 64.

Figure 13B illustrates an alternative method of selecting the camera position by using a camera selection window 130 which includes a series of thumbnail icons 133, each thumbnail icon comprising a thumbnail image derived from the image data obtained from a respective camera

position. The user may thereby select from the displayed thumbnail images the appropriate camera position for viewing the required aspect of the object represented by the model image and by clicking the mouse 103 when cursor 33 is on the thumbnail icon 133, generates a pointing signal 112 received at step 174 of Figure 17 by the apparatus, thereby enabling the required camera position to be determined as a centre of projection.

In the above described example, the centre of projection for projecting the new model point onto the surface of the model is defined as being the centre of the camera. The centre of projection may alternatively be defined in terms of the point in the image plane of the camera corresponding to the location of the image point corresponding to the new model point. For example, in Figure 19, a camera image 30 is displayed in a camera image window 190 to allow the user to select a camera image point 191 determined by the user to correspond to the new model point 64. As illustrated in the flowchart of Figure 21, the co-ordinates of the camera image point are input at step 210 to enable the apparatus to calculate at step 211 the ray in the model space through the co-ordinates of the added model point and camera image point as illustrated in Figure 20 where the position 200 of the camera image point in the camera plane 201 is used to determine the trajectory of the ray

140.

Alternative devices may be used in place of the computer mouse 103 for the input of selection signals, including for example any conventional pointing device such as a touch screen or touch pad device. Alternatively, a keyboard 104 may be used for the input of commands or co-ordinates.

In the method of Figure 17, the user may choose to change from one mode to another at any time by selecting one of the mode icons 230.

The method of the above aspect of the present invention described with reference to Figures 1, 10, and 12 to 20 can be implemented by a computer program operating on the computer apparatus 100, the program comprising processor implementable instructions for controlling the processor 101. The program may be stored in a storage medium such as floppy disk 106. An aspect of the present invention thus provides a storage medium storing processor implementable instructions for carrying out the above described method.

Further, the computer program may be obtained in electronic form for example by downloading the program code as a signal 111 over a network such as the internet

via the modem 110.

A further aspect of the present embodiment will now be described using corresponding reference numerals to those of preceding figures where appropriate for corresponding elements. This aspect of the embodiment relates to the provision of a method and apparatus enabling an interface to allow a user to evaluate the quality of a model of the type discussed above, and in particular of the type discussed with reference to Figure 1 using the apparatus described above with reference to Figure 10.

As previously discussed, a user may adopt one of a number of techniques for refining and editing model data in order to achieve an improved model image. In order to evaluate the quality of the model image, this aspect of the embodiment allows views of the model image and camera image to be presented in respective model image windows and camera image windows on the display screen and for the respective images to be presented such that both the camera image and model image represent views of the object from substantially the same viewpoint and in respect of which substantially the same image settings such as magnification, field of view, etc, are provided (these latter parameters are referred to below as "camera intrinsics").

Figure 22 illustrates the relationship between a physical object 220 which is the subject of the modelling exercise and a set of camera positions L(i), relative to the object 220, from which a set of frames of image data are obtained, a corresponding camera image I(i) being obtained. The camera images may be obtained by moving a single camera successively into the camera positions L(i), by having a set of different cameras or by moving the object relative to a stationary camera, for example.

Having obtained model data allowing model images to be displayed, the user wishes to evaluate the model by displaying side by side a camera image and a model image. In Figure 22, camera position L(3) is of particular interest to the user.

Using the apparatus of Figure 10, the user operates the apparatus to achieve this result using the method steps illustrated in the flowchart of Figure 24 which will be illustrated below with reference to Figure 23.

At step 240, the user selects the required mode of operation for displaying camera and model images for the purpose of evaluation, mode selection being achieved using the interface provided by the display screen 107, the cursor 33 and the mouse 103 to select one of the mode icons 230 located in a peripheral region of the display

screen as shown in Figure 23.

At step 241, the apparatus generates camera image data for each of the frames of image data, using the thumbnail image format, and displays the thumbnail images as icons 231 within an icon window 232 of the display screen 107.

The icons 231 are displayed in a sequence as calculated by camera position calculation module 6 which corresponds to the spatial relationship of the positions L(i) as shown in Figure 22, so that the sequence L(i), i = 1 to n progressing from left to right is maintained in the layout of the icons on the display screen 107 such that images I(i), i = 1 to n, are positioned from left to right according to the value of i.

For simplicity of representation, the images shown in Figure 23 are those of a regular polyhedron in which an x is drawn on one of the faces so that the apparent position of the x in each of the displayed thumbnail images corresponds to the view which would be obtained from the camera positions L(i).

At step 242 the user views the icons and at step 243 the user selects one of the icons as being of particular relevance for the purpose of evaluation of the images. The user selects the icon as indicated in Figure 23 by

the cursor 33 overlaying the third image, i = 3, corresponding to selection of the camera position L(3) of Figure 22.

At step 244, the apparatus receives the icon selection input and at step 245, the apparatus identifies the selected camera image for display in a camera image window 109. At step 246, the apparatus determines the position data for the selected camera by accessing data stored with the camera image data and at step 247 calculates the model image data using the selected position data to define the viewpoint for the model. In calculating the model image data, the apparatus also uses camera intrinsic parameters stored with the camera image data. The intrinsic parameters of the camera comprise the focal length, the pixel aspect ratio, the first order radial distortion coefficient, the skew angle (between the axes of the pixel grid) and the principal point (at which the camera optical axis intersects the viewing plane).

At step 248, the apparatus displays a model image 20 in the model image window 108 and the camera image 30 in a camera image window 109, thereby allowing the user to view and compare the selected camera image and the model image as calculated from a corresponding viewpoint.

In Figure 23, the icons 231 are linked in series by links 233. If necessary, a large number of such icons may be displayed in an array comprising a number of rows, maintaining the links between successive icons in order to visually indicate the continuity of the sequence (i.e. the direction of increasing i). The use of such links therefore assists in providing the user with an indication of where the most appropriate image is to be selected.

After viewing the images for a selected viewpoint, the user may then choose to view camera and model images for different viewpoints by selecting different icons, repeating step 243 of Figure 24, and resulting in the apparatus repeating steps 244 to 248 to enable the further views to be seen.

If the user then decides that the model data requires editing, the user may then select a different mode of operation by selecting the appropriate mode icon 230 for further operation of the apparatus.

An alternative embodiment will now be described with reference to Figure 25 and the flowchart of Figure 26. Referring to Figure 26, at step 260 the user selects a required mode of operation by selecting the appropriate mode icon 230 of Figure 25. The apparatus responds by

generating and displaying icons 250 in a camera position window 251.

Within the camera position window 251, a display generated by the apparatus at step 261 comprises a representation 252 of the object based upon the model data together with representations of cameras at positions L(i), i = 1 to n, such that the relative positions of the cameras and the representation 252 correspond to the calculated camera positions developed by the camera position calculation module 6 of Figure 1. The representation 252 is thereby placed at the origin of the co-ordinate system of the model and the icons 250 located in effect at the calculated camera positions.

This representation of the relative positions of the cameras and object allows the user to easily select a viewing point for the camera and model images to be displayed. In order to select a particular viewpoint, the user at step 262 views the icons 250 within the window 251 and at step 263 selects one of the icons at the desired camera position. The apparatus responds at step 265 by identifying the camera image data corresponding to the selected camera position. At step 266, the apparatus then proceeds to calculate the model image data using the selected position data as a viewpoint and using camera intrinsic parameters stored in

conjunction with the camera image data identified in step 265.

At step 267, the apparatus then displays the model image in model image window 108 and the camera image 30 in camera image window 109 to be viewed by the user at step 268. The user is then able to evaluate the quality of the image by comparison between the images.

In each of the display interfaces of Figures 23 and 25, the camera image window 109 and the model image window 108 may be moved relative to one another using a drag and drop method by means of actuating the mouse. Similarly, the icon windows 232 and 251 may be moved relative to the image windows 108 and 109, thereby allowing the user to arrange the windows for maximum ease of selection and comparison.

The method of the present invention can be implemented by a computer program operating on the computer apparatus 100, the program comprising processor implementable instructions for controlling the processor 101. The program may be stored in a storage medium such as floppy disk 106. An aspect of the present invention thus provides a storage medium storing processor implementable instructions for carrying out the above described method.

Further, the computer program may be obtained in electronic form for example by downloading the program code as a signal 111 over a network such as the internet via the modem 110.

The present application incorporates by cross-reference the full contents of the applicant's following co-pending applications: 9927876.4 (attorney ref: 2635901); 9927875.6 (attorney ref: 2636501); 9927906.9 (attorney ref: 2641601); 9927907.7 (attorney ref: 2641701); 9927909.3 (attorney ref: 2641901); 9929957.0 (attorney ref: 2641001); 0001300.3 (attorney ref: 2636001) and 0018492.9 (attorney ref: 2635801).

ANNEX A

1. CORNER DETECTION

1.1 Summary

This process described below calculates corner points, to sub-pixel accuracy, from a single grey scale or colour image. It does this by first detecting edge boundaries in the image and then choosing corner points to be points where a strong edge changes direction rapidly. The method is based on the facet model of corner detection, described in Haralick and Shapiro[i].

1.2 Algorithm

The algorithm has four stages:

(1) Create grey scale image (if necessary);
(2) Calculate edge strengths and directions;
(3) Calculate edge boundaries;
(4) Calculate corner points.

1.2.1 Create grey scale image

The corner detection method works on grey scale images. For colour images, the colour values are first converted

to floating point grey scale values using the formula:

$$grey\_scale = (0.3 \times red) + (0.59 \times green) + (0.11 \times blue) \quad \ldots\text{A-1}$$

This is the standard definition of brightness as defined by NTSC and described in Foley and van Dam[ii].

1.2.2 Calculate edge strengths and directions

The edge strengths and directions are calculated using the 7x7 integrated directional derivative gradient operator discussed in section 8.9 of Haralick and Shapiro[i].

The row and column forms of the derivative operator are both applied to each pixel in the grey scale image. The results are combined in the standard way to calculate the edge strength and edge direction at each pixel.

The output of this part of the algorithm is a complete derivative image.

1.2.3 Calculate edge boundaries

The edge boundaries are calculated by using a zero crossing edge detection method based on a set of 5x5 kernels describing a bivariate cubic fit to the neighbourhood of each pixel.

The edge boundary detection method places an edge at all pixels which are close to a negatively sloped zero crossing of the second directional derivative taken in the direction of the gradient, where the derivatives are defined using the bivariate cubic fit to the grey level surface. The subpixel location of the zero crossing is also stored along with the pixel location.

The method of edge boundary detection is described in more detail in section 8.8.4 of Haralick and Shapiro[1].

1.2.4 <u>Calculate corner points</u>

The corner points are calculated using a method which uses the edge boundaries calculated in the previous step.

Corners are associated with two conditions:

(1) the occurrence of an edge boundary; and

(2) significant changes in edge direction.

Each of the pixels on the edge boundary is tested for "cornerness" by considering two points equidistant to it along the tangent direction. If the change in the edge direction is greater than a given threshold then the point is labelled as a corner. This step is described in section 8.10.1 of Haralick and Shapiro[i].

Finally the corners are sorted on the product of the edge strength magnitude and the change of edge direction. The top 200 corners which are separated by at least 5 pixels are output.

2. FEATURE TRACKING

2.1 Summary

This process described below tracks feature points (typically corners) across a sequence of grey scale or colour images.

The tracking method uses a constant image velocity Kalman filter to predict the motion of the corners, and a correlation based matcher to make the measurements of corner correspondences.

The method assumes that the motion of corners is smooth enough across the sequence of input images that a constant velocity Kalman filter is useful, and that corner measurements and motion can be modelled by gaussians.

2.2 Algorithm

1) Input corners from an image.

2) Predict forward using Kalman filter.

3) If the position uncertainty of the predicted corner

is greater than a threshold, Δ, as measured by the state positional variance, drop the corner from the list of currently tracked corners.

4) Input a new image from the sequence.

5) For each of the currently tracked corners:

   a) search a window in the new image for pixels which match the corner;

   b) update the corresponding Kalman filter, using any new observations (i.e. matches).

6) Input the corners from the new image as new points to be tracked (first, filtering them to remove any which are too close to existing tracked points).

7) Go back to (2)

2.2.1 <u>Prediction</u>

This uses the following standard Kalman filter equations for prediction, assuming a constant velocity and random

uniform gaussian acceleration model for the dynamics:

$$X_{n+1} = \Theta_{n+1,n} X_n \qquad \text{....A-2}$$

$$K_{n+1} = \Theta_{n+1,n} K_n \Theta^T_{n+1,n} + Q_n \qquad \text{....A-3}$$

where x is the 4D state of the system, (defined by the position and velocity vector of the corner), K is the state covariance matrix, Θ is the transition matrix, and Q is the process covariance matrix.

In this model, the transition matrix and process covariance matrix are constant and have the following values:

$$\Theta_{n+1,n} = \begin{pmatrix} I & I \\ 0 & I \end{pmatrix} \qquad \text{....A-4}$$

$$Q_n = \begin{pmatrix} 0 & 0 \\ 0 & \sigma_v^2 I \end{pmatrix} \qquad \text{....A-5}$$

2.2.2 <u>Searching and matching</u>

This uses the positional uncertainty (given by the top two diagonal elements of the state covariance matrix, K) to define a region in which to search for new measurements (i.e. a range gate).

The range gate is a rectangular region of dimensions:

$$\Delta x = \sqrt{K_{11}},\ \Delta y = \sqrt{K_{22}} \qquad \text{....A-6}$$

The correlation score between a window around the previously measured corner and each of the pixels in the range gate is calculated.

The two top correlation scores are kept.

If the top correlation score is larger than a threshold, C_0, and the difference between the two top correlation scores is larger than a threshold ΔC, then the pixel with the top correlation score is kept as the latest measurement.

2.2.3 <u>Update</u>

The measurement is used to update the Kalman filter in the standard way:

$$G = KH^T(HKH^T+R)^{-1} \quad \text{....A-7}$$

$$x \rightarrow x+G(\hat{x}-Hx) \quad \text{....A-8}$$

$$K \rightarrow (I-GH)K \quad \text{....A-9}$$

where G is the Kalman gain, H is the measurement matrix, and R is the measurement covariance matrix.

In this implementation, the measurement matrix and measurement covariance matrix are both constant, being given by:

$$H = (I\ 0) \quad \text{....A-10}$$

$$R = \sigma^2 I \quad \text{....A-11}$$

2.2.4 Parameters

The parameters of the algorithm are:

Initial conditions: x_0 and K_0.

Process velocity variance: σ_v^2.

Measurement variance: σ^2.

Position uncertainty threshold for loss of track: Δ.

Covariance threshold: C_0.

Matching ambiguity threshold: ΔC.

For the initial conditions, the position of the first corner measurement and zero velocity are used, with an initial covariance matrix of the form:

$$K_0 = \begin{pmatrix} 0 & 0 \\ 0 & \sigma_0^2 I \end{pmatrix} \quad \text{....A-12}$$

σ_0^2 is set to $\sigma_0^2 = 200(\text{pixels/frame})^2$.

The algorithm's behaviour over a long sequence is anyway not too dependent on the initial conditions.

The process velocity variance is set to the fixed value of 50 (pixels/frame)^2. The process velocity variance would have to be increased above this for a hand-held sequence. In fact it is straightforward to obtain a reasonable value for the process velocity variance adaptively.

The measurement variance is obtained from the following model:

$$\sigma^2 = (rK+a) \qquad \text{....A-13}$$

where $K = \sqrt{(K_{11}K_{22})}$ is a measure of the positional uncertainty, r is a parameter related to the likelihood of obtaining an outlier, and a is a parameter related to the measurement uncertainty of inliers. "r" and "a" are set to r=0.1 and a=1.0.

This model takes into account, in a heuristic way, the fact that it is more likely that an outlier will be obtained if the range gate is large.

The measurement variance (in fact the full measurement covariance matrix R) could also be obtained from the behaviour of the auto-correlation in the neighbourhood of the measurement. However this would not take into account the likelihood of obtaining an outlier.

The remaining parameters are set to the values: Δ=400 pixels^2, C_0=0.9 and ΔC=0.001.

3. 3D SURFACE GENERATION

3.1 Architecture

In the method described below, it is assumed that the object can be segmented from the background in a set of images completely surrounding the object. Although this restricts the generality of the method, this constraint can often be arranged in practice, particularly for small objects.

The method consists of five processes, which are run consecutively:

- First, for all the images in which the camera positions and orientations have been calculated, the object is segmented from the background, using colour information. This produces a set of binary images, where the pixels are marked as being either object or background.

- The segmentations are used, together with the camera positions and orientations, to generate a voxel carving, consisting of a 3D grid of voxels enclosing the object. Each of the voxels is marked as being either object or empty space.

- The voxel carving is turned into a 3D surface triangulation, using a standard triangulation algorithm (marching cubes).

- The number of triangles is reduced substantially by passing the triangulation through a decimation process.

- Finally the triangulation is textured, using appropriate parts of the original images to provide the texturing on the triangles.

3.2 Segmentation

The aim of this process is to segment an object (in front of a reasonably homogeneous coloured background) in an image using colour information. The resulting binary image is used in voxel carving.

Two alternative methods are used:

Method 1: input a single RGB colour value representing the background colour - each RGB pixel in the image is examined and if the Euclidean distance to the background colour (in RGB space) is less than a specified threshold the pixel is labelled as background (BLACK).

Method 2: input a "blue" image containing a representative region of the background.

The algorithm has two stages:

(1) Build a hash table of quantised background colours

(2) Use the table to segment each image.

Step 1) Build hash table

Go through each RGB pixel, p, in the "blue" background image.

Set q to be a quantised version of p. Explicitly:

$$q = (p+t/2)/t \qquad \text{....A-14}$$

where t is a threshold determining how near RGB values need to be to background colours to be labelled as background.

The quantisation step has two effects:

1) reducing the number of RGB pixel values, thus increasing the efficiency of hashing;

2) defining the threshold for how close a RGB pixel has to be to a background colour pixel to be labelled as background.

q is now added to a hash table (if not already in the

table) using the (integer) hashing function

$$h(q) = (q\_red \ \& \ 7)*2\text{^}6+(q\_green \ \& \ 7)*2\text{^}3+(q\_blue \ \& \ 7) \quad \text{....A-15}$$

That is, the 3 least significant bits of each colour field are used. This function is chosen to try and spread out the data into the available bins. Ideally each bin in the hash table has a small number of colour entries. Each quantised colour RGB triple is only added once to the table (the frequency of a value is irrelevant).

Step 2) Segment each image

Go through each RGB pixel, v, in each image.

Set w to be the quantised version of v as before.

To decide whether w is in the hash table, explicitly look at all the entries in the bin with index h(w) and see if any of them are the same as w. If yes, then v is a background pixel - set the corresponding pixel in the output image to BLACK. If no then v is a foreground

pixel - set the corresponding pixel in the output image to WHITE

Post Processing: For both methods a post process is performed to fill small holes and remove small isolated regions.

A median filter is used with a circular window. (A circular window is chosen to avoid biasing the result in the x or y directions).

Build a circular mask of radius r. Explicitly store the start and end values for each scan line on the circle.

Go through each pixel in the binary image.

Place the centre of the mask on the current pixel. Count the number of BLACK pixels and the number of WHITE pixels in the circular region.

If (#WHITE pixels ≥ #BLACK pixels) then set corresponding output pixel to WHITE. Otherwise output pixel is BLACK.

3.3 Voxel carving

The aim of this process is to produce a 3D voxel grid, enclosing the object, with each of the voxels marked as either object or empty space.

The input to the algorithm is:

- a set of binary segmentation images, each of which is associated with a camera position and orientation;

- 2 sets of 3D co-ordinates, (xmin, ymin, zmin) and (xmax, ymax, zmax), describing the opposite vertices of a cube surrounding the object;

- a parameter, n, giving the number of voxels required in the voxel grid.

A pre-processing step calculates a suitable size for the voxels (they are cubes) and the 3D locations of the

voxels, using n, (xmin, ymin, zmin) and (xmax, ymax, zmax).

Then, for each of the voxels in the grid, the mid-point of the voxel cube is projected into each of the segmentation images. If the projected point falls onto a pixel which is marked as background, on any of the images, then the corresponding voxel is marked as empty space, otherwise it is marked as belonging to the object.

Voxel carving is described further in "Rapid Octree Construction from Image Sequences" by R. Szeliski in CVGIP: Image Understanding, Volume 58, Number 1, July 1993, pages 23-32.

3.4 <u>Marching cubes</u>

The aim of the process is to produce a surface triangulation from a set of samples of an implicit function representing the surface (for instance a signed distance function). In the case where the implicit function has been obtained from a voxel carve, the

implicit function takes the value -1 for samples which are inside the object and +1 for samples which are outside the object.

Marching cubes is an algorithm that takes a set of samples of an implicit surface (e.g. a signed distance function) sampled at regular intervals on a voxel grid, and extracts a triangulated surface mesh. Lorensen and Cline[iii] and Bloomenthal[iv] give details on the algorithm and its implementation.

The marching-cubes algorithm constructs a surface mesh by "marching" around the cubes while following the zero crossings of the implicit surface f(x)=0, adding to the triangulation as it goes. The signed distance allows the marching-cubes algorithm to interpolate the location of the surface with higher accuracy than the resolution of the volume grid. The marching cubes algorithm can be used as a continuation method (i.e. it finds an initial surface point and extends the surface from this point).

3.5 <u>Decimation</u>

The aim of the process is to reduce the number of triangles in the model, making the model more compact and therefore easier to load and render in real time.

The process reads in a triangular mesh and then randomly removes each vertex to see if the vertex contributes to the shape of the surface or not. (i.e. if the hole is filled, is the vertex a "long" way from the filled hole). Vertices which do not contribute to the shape are kept out of the triangulation. This results in fewer vertices (and hence triangles) in the final model.

The algorithm is described below in pseudo-code.

INPUT
Read in vertices
Read in triples of vertex IDs making up triangles

PROCESSING
Repeat NVERTEX times
    Choose a random vertex, V, which hasn't been chosen before
    Locate set of all triangles having V as a vertex, S
    Order S so adjacent triangles are next to each

other

Re-triangulate triangle set, ignoring V (i.e. remove selected triangles & V and then fill in hole)

Find the maximum distance between V and the plane of each triangle

If (distance < threshold)

Discard V and keep new triangulation

Else

Keep V and return to old triangulation

OUTPUT

Output list of kept vertices

Output updated list of triangles

The process therefore combines adjacent triangles in the model produced by the marching cubes algorithm, if this can be done without introducing large errors into the model.

The selection of the vertices is carried out in a random order in order to avoid the effect of gradually eroding a large part of the surface by consecutively removing neighbouring vertices.

3.6 <u>Further Surface Generation Techniques</u>

Further techniques which may be employed to generate a 3D computer model of an object surface include voxel colouring, for example as described in "Photorealistic Scene Reconstruction by Voxel Coloring" by Seitz and Dyer in Proc. Conf. Computer Vision and Pattern Recognition 1997, p1067-1073, "Plenoptic Image Editing" by Seitz and Kutulakos in Proc. 6th International Conference on Computer Vision, pp 17-24, "What Do N Photographs Tell Us About 3D Shape?" by Kutulakos and Seitz in University of Rochester Computer Sciences Technical Report 680, January 1998, and "A Theory of Shape by Space Carving" by Kutulakos and Seitz in University of Rochester Computer Sciences Technical Report 692, May 1998.

4. <u>TEXTURING</u>

The aim of the process is to texture each surface polygon (typically a triangle) with the most appropriate image texture. The output of the process is a VRML model of the surface, complete with texture co-ordinates.

The triangle having the largest projected area is a good

triangle to use for texturing, as it is the triangle for which the texture will appear at highest resolution.

A good approximation to the triangle with the largest projected area, under the assumption that there is no substantial difference in scale between the different images, can be obtained in the following way.

For each surface triangle, the image "i" is found such that the triangle is the most front facing (i.e. having the greatest value for $\hat{n}_t.\hat{v}_i$, where $\hat{n}_t$ is the triangle normal and $\hat{v}_i$ is the viewing direction for the "i" th camera). The vertices of the projected triangle are then used as texture co-ordinates in the resulting VRML model.

This technique can fail where there is a substantial amount of self-occlusion, or several objects occluding each other. This is because the technique does not take into account the fact that the object may occlude the selected triangle. However, in practice this does not appear to be much of a problem.

It has been found that, if every image is used for texturing then this can result in very large VRML models being produced. These can be cumbersome to load and render in real time. Therefore, in practice, a subset of images is used to texture the model. This subset may be specified in a configuration file.

References

i R M Haralick and L G Shapiro: "Computer and Robot Vision Volume 1", Addison-Wesley, 1992, ISBN 0-201-10877-1 (v.1), section 8.

ii J Foley, A van Dam, S Feiner and J Hughes: "Computer Graphics: Principles and Practice", Addison-Wesley, ISBN 0-201-12110-7.

iii W.E. Lorensen and H.E.Cline: "Marching Cubes: A High Resolution 3D Surface Construction Algorithm", in Computer Graphics, SIGGRAPH 87 proceedings, 21: 163-169, July 1987.

iv J. Bloomenthal: "An Implicit Surface Polygonizer", Graphics Gems IV, AP Professional, 1994, ISBN 0123361559, pp 324-350.

CLAIMS

1. A method of operating an apparatus for generating model data representative of a model in a three dimensional space from image data representative of a set of camera images of an object;

the apparatus performing the steps of;

displaying a model image based on an existing set of model data;

displaying one of the camera images of the object for selection by a user of an additional feature to be represented by additional model data;

receiving an image point selection signal responsive to user actuation of an input means and identifying co-ordinates of an image point in the camera image defining the selected additional feature;

calculating a locus in the three dimensional space defining positions of possible model points corresponding to the image point and consistent with the geometric relationship between the object and a camera position from which the displayed camera image was taken;

displaying a position indicator in the model image at co-ordinates in the model image corresponding to one of the possible model points on the locus;

receiving positioning signals responsive to user actuation of the input means and updating the co-ordinates of the position indicator such that movement of the position indicator is constrained to follow a

trajectory in the model image corresponding to the locus;

receiving a model point selecting signal responsive to user actuation of the input means and determining selected co-ordinates of the position indicator to be the position indicator co-ordinates at the time of receiving the model point selecting signal; and

determining co-ordinates of the additional model point in the three dimensional space corresponding to the selected co-ordinates of the position indicator.

2. A method as claimed in claim 1 including displaying in the model image a line representing the locus.

3. A method as claimed in any preceding claim wherein the locus is a straight line in the three dimensional space.

4. A method as claimed in any preceding claim wherein the input means comprises a computer mouse and wherein said positioning signals are responsive to user actuation of the mouse by clicking the mouse during movement and releasing the mouse at a selected position to generate the model point selecting signal.

5. A method as claimed in any preceding claim including the step of displaying a symbol representative of the additional model point at a model image point

corresponding to the selected co-ordinates.

6. A method as claimed in claim 5 comprising the further step of editing the position of the additional model point in response to receiving further positioning signals and model point selecting signals responsive to user actuation of the input means.

7. A method as claimed in any preceding claim including the further step of receiving a processing instruction signal and, responsive to said signal, implementing a model generating process to incorporate the additional model point into the model data.

8. A method as claimed in claim 7 including the step of generating surface elements of the model from the model data including the additional model point and displaying said surface elements in the model image.

9. Apparatus for generating model data representative of a model in a three dimensional space from image data representative of a set of camera images of an object;

the apparatus comprising;

an interface comprising display means operable to display images to a user and input means responsive to user actuation;

control means operable to control the display means

to display a model image based on an existing set of model data and to display one of the camera images of the object for selection by a user of an additional feature to be represented by additional model data;

receiving means for receiving an image point selection signal responsive to user actuation of the input means and identifying co-ordinates of an image point in the camera image defining the selected additional feature;

calculating means for calculating a locus in the three dimensional space defining positions of possible model points corresponding to the image point and consistent with the geometric relationship between the object and a camera position from which the displayed camera image was taken;

the control means being further operable to control the display means to display a position indicator in the model image at co-ordinates in the model image corresponding to one of the possible model points on the locus;

the apparatus further comprising means for receiving positioning signals responsive to user actuation of the input means and updating the co-ordinates of the position indicator such that movement of the position indicator is constrained to follow a trajectory in the model image corresponding to the locus;

means for receiving a model point selecting signal

responsive to user actuation of the input means and determining selected co-ordinates of the position indicator to be the position indicator co-ordinates at the time of receiving the model point selecting signal; and

means for determining co-ordinates of the additional model point in the three dimensional space corresponding to the selected co-ordinates of the position indicator.

10. Apparatus as claimed in claim 9 wherein the control means is operable to control the display means to display in the model image a line representing the locus.

11. Apparatus as claimed in any of claims 9 and 10 wherein the calculating means is operable to calculate the locus as a straight line in the three dimensional space.

12. Apparatus as claimed in any of claims 9 to 11 wherein the input means comprises a computer mouse and wherein said positioning signals are responsive to user actuation of the mouse by clicking the mouse during movement and releasing the mouse at a selected position to generate the model point selecting signal.

13. Apparatus as claimed in any of claims 9 to 12 wherein the control means is operable to control the

display means to display a symbol representative of the additional model point at a model image point corresponding to the selected co-ordinates.

14. Apparatus as claimed in claim 13 comprising editing means for editing the position of the additional model point in response to receiving further positioning signals and model point selecting signals responsive to user actuation of the input means.

15. Apparatus as claimed in any of claims 9 to 14 including model generating means operable to receive a processing instruction signal and, responsive to said signal, to implement a model generating process to incorporate the additional model point into the model data.

16. Apparatus as claimed in claim 15 wherein the model generating means is operable to generate surface elements of the model from the model data including the additional model point and wherein the control means is operable to control the display to display said surface elements in the model image.

17. A computer program comprising processor implementable instructions for carrying out a method as claimed in any of claims 1 to 8.

18. A storage medium storing processor implementable instructions for controlling a processor to carry out a method as claimed in any of claims 1 to 8.

19. An electrical signal carrying processor implementable instructions for controlling a processor to carry out a method as claimed in any of claims 1 to 8.

20. A method of operating an apparatus for generating model data defining a model in a three dimensional space, the model data comprising co-ordinates defining model points and surface elements generated with reference to the model points; the method comprising editing an existing set of model data by the steps of;

adding a new model point to the existing set of model data;

projecting the new model point onto the model and identifying a selected one of the surface elements onto which the new model point is projected;

identifying a subset of the model points which define the generation of the selected surface element;

adding the new model point to the subset to form an edited subset of model points; and

generating one or more edited surface elements from the edited subset of model points to replace the selected surface element.

21. A method as claimed in claim 20 wherein the projecting step comprises receiving input data defining a centre of projection and projecting the new model point onto the model in a direction of projection along a ray generated through the centre of projection and the new model point.

22. A method as claimed in claim 21 wherein the existing set of model data is generated by processing image data representative of camera images of an object to be modelled.

23. A method as claimed in claim 22 wherein the step of receiving input data comprises receiving an image selection signal for selecting one of said camera images, and defining the centre of projection for projecting the model point to be co-ordinates representative of a camera position from which the selected camera image was taken.

24. A method as claimed in claim 23 including the step of displaying a set of camera images and receiving a selection signal responsive to user actuation of an input means to select the selected camera image.

25. A method as claimed in claim 22 wherein the step of receiving input data comprises receiving an image

selection signal for selecting one of said camera images, and receiving an image point selection signal defining co-ordinates of an image point in said selected camera image corresponding to the new model point.

26. A method as claimed in claim 25 including the step of calculating in the three dimensional space co-ordinates of the centre of projection to correspond to the position of the image point in an image plane of the camera.

27. A method as claimed in any of claims 21 to 26 including the step of determining whether a plurality of surface elements are intersected by the ray and, if so, determining the selected surface to be whichever of the intersected surface elements is closest to the new model point.

28. A method as claimed in any of claims 20 to 27 wherein the surface elements comprise triangular facets and wherein each subset of the model points defining the generation of the selected surface element comprises three model points constituting apices of the triangular facets.

29. Apparatus for generating model data defining a model in a three dimensional space, the model data comprising

co-ordinates defining model points and surface elements generated with reference to the model points, the apparatus being operable to edit an existing set of model data and comprising;

means for adding a new model point to the existing set of model data;

means for projecting the new model point onto the model and identifying a selected one of the surface elements onto which the new model point is projected;

means for identifying a subset of the model points which define the generation of the selected surface element;

means for adding the new model point to the subset to form an edited subset of model points; and

means for generating one or more edited surface elements from the edited subset of model points to replace the selected surface element.

30. Apparatus as claimed in claim 29 wherein the projecting means comprises receiving means for receiving input data defining a centre of projection, the projecting means being operable to project the new model point onto the model in a direction of projection along a ray generated through the centre of projection and the new model point.

31. Apparatus as claimed in claim 30 wherein the

existing set of model data is generated by processing image data representative of camera images of an object to be modelled.

32. Apparatus as claimed in claim 31 wherein the receiving means is operable to receive an image selection signal for selecting one of said camera images, and to define the centre of projection for projecting the model point to be co-ordinates representative of a camera position from which the selected camera image was taken.

33. Apparatus as claimed in claim 32 comprising interface means for displaying a set of camera images and receiving a selection signal responsive to user actuation of an input means to select the selected camera image.

34. Apparatus as claimed in claim 31 wherein the receiving means is operable to receive an image selection signal for selecting one of said camera images, and to receive an image point selection signal defining co-ordinates of an image point in said selected camera image corresponding to the new model point.

35. Apparatus as claimed in claim 34 including calculating means for calculating in the three dimensional space co-ordinates of the centre of projection to correspond to the position of the image

point in an image plane of the camera.

36. Apparatus as claimed in any of claims 30 to 35 including means for determining whether a plurality of surface elements are intersected by the ray and, if so, determining the selected surface to be whichever of the intersected surface elements is closest to the new model point.

37. Apparatus as claimed in any of claims 30 to 36 wherein the surface elements comprise triangular facets and wherein each subset of the model points defining the generation of the selected surface element comprises three model points constituting apices of the triangular facets.

38. A computer program comprising processor implementable instructions for carrying out a method as claimed in any of claims 20 to 28.

39. A storage medium storing processor implementable instructions for controlling a processor to carry out a method as claimed in any of claims 20 to 28.

40. An electrical signal carrying processor implementable instructions for controlling a processor to carry out a method as claimed in any of claims 20 to 28.

41. A method of operating an apparatus for generating model data representative of a three dimensional model of an object from input signals representative of a set of camera images of the object taken from a plurality of camera positions, the method comprising;

displaying a set of icons, each being associated with a respective one of the camera images of the object;

receiving a selection signal responsive to user actuation of an input means whereby the selection signal identifies a selected one of the icons;

determining a selected camera image from the set of camera images corresponding to the selected icon;

displaying the selected image;

determining position data representative of a selected camera position from which the selected image was taken;

generating in accordance with said model a model image representative of a view of the model from a viewpoint corresponding to the position data; and

displaying the model image for visual comparison with the selected image by the user.

42. A method as claimed in claim 41 including the step of generating the icons in response to receiving a mode selection input.

43. A method as claimed in any of claims 41 and 42

wherein the icons are generated as thumbnail images of the respective camera images.

44. A method as claimed in claim 43 wherein the step of displaying the set of icons comprises displaying the icons in an array and displaying links between the icons such that each pair of icons corresponding to adjacent camera positions in a positional sequence of the camera positions is joined by a respective link.

45. A method as claimed in claim 44 wherein the icons are displayed in a linear array.

46. A method as claimed in any of claims 41 to 45 wherein the selected camera image and the model image are displayed in respective windows and including the step of providing relative movement of the windows in response to receiving window movement input signals.

47. A method as claimed in claim 46 wherein the icons are displayed in a further window and including the step of facilitating movement of the further window relative to the image windows in response to window movement input signals.

48. A method as claimed in any of claims 41 to 47 comprising generating the selection signal by operation

of a pointing means for user actuation in selecting one of the displayed icons.

49. A method as claimed in claim 41 wherein displaying the set of icons comprises displaying a view of the model from a viewpoint in which the icons comprise representations of cameras and are shown at respective positions relative to the model which correspond substantially to the camera positions relative to the object.

50. Apparatus for generating model data representative of a three dimensional model of an object from input signals representative of a set of camera images of the object taken from a plurality of camera positions, the apparatus comprising;

display means for displaying a set of icons, each being associated with a respective one of the camera images of the object;

means for receiving a selection signal responsive to user actuation of an input means whereby the selection signal identifies a selected one of the icons;

means for determining a selected camera image from the set of camera images corresponding to the selected icon whereby the display means is operable to display the selected image;

means for determining position data representative

of a selected camera position from which the selected image was taken;

means for generating in accordance with said model a model image representative of a view of the model from a viewpoint corresponding to the position data; and control means for controlling the display means to display the model image for visual comparison with the selected image by the user.

51. Apparatus as claimed in claim 50 further comprising means for generating the icons in response to receiving a mode selection input.

52. Apparatus as claimed in any of claims 50 and 51 wherein icon generating means is operable to generate the icons as thumbnail images of the respective camera images.

53. Apparatus as claimed in claim 52 wherein the control means is operable to control the display means to display the set of icons in an array and to display links between the icons such that each pair of icons corresponding to adjacent camera positions in a positional sequence of the camera positions is joined by a respective link.

54. Apparatus as claimed in claim 53 wherein the control means is operable to control the display means to

display the icons in a linear array.

55. Apparatus as claimed in any of claims 50 to 54 wherein control means is operable control the display means to display the selected camera image and the model image in respective windows and to provide relative movement of the windows in response to receiving window movement input signals.

56. Apparatus as claimed in claim 55 wherein the control means is operable to control the display means to display the icons in a further window to facilitate movement of the further window relative to the camera image window and model image window in response to window movement input signals.

57. Apparatus as claimed in any of claims 50 to 56 wherein the means for generating the selection signal comprises a pointing means for user actuation in selecting one of the displayed icons.

58. Apparatus as claimed in claim 50 wherein the control means is operable to control the display means for displaying the set of icons by displaying a view of the model from a viewpoint in which the icons comprise representations of cameras and are shown at respective positions relative to the model which correspond

substantially to the camera positions relative to the object.

59. A computer program comprising processor implementable instructions for carrying out a method as claimed in any of claims 41 to 49.

60. A storage medium storing processor implementable instructions for controlling a processor to carry out a method as claimed in any of claims 41 to 49.

61. An electrical signal carrying processor implementable instructions for controlling a processor to carry out a method as claimed in any of claims 41 to 49.

62. In a method of operating an apparatus for generating model data representative of a model in a three dimensional space from image data representative of a set of camera images of an object, an improvement comprising;

the apparatus performing the steps of;

displaying a model image based on an existing set of model data;

displaying one of the camera images of the object for selection by a user of an additional feature to be represented by additional model data;

receiving an image point selection signal responsive to user actuation of an input means and identifying co-

ordinates of an image point in the camera image defining the selected additional feature;

calculating a locus in the three dimensional space defining positions of possible model points corresponding to the image point and consistent with the geometric relationship between the object and a camera position from which the displayed camera image was taken;

displaying a position indicator in the model image at co-ordinates in the model image corresponding to one of the possible model points on the locus;

receiving positioning signals responsive to user actuation of the input means and updating the co-ordinates of the position indicator such that movement of the position indicator is constrained to follow a trajectory in the model image corresponding to the locus;

receiving a model point selecting signal responsive to user actuation of the input means and determining selected co-ordinates of the position indicator to be the position indicator co-ordinates at the time of receiving the model point selecting signal; and

determining co-ordinates of the additional model point in the three dimensional space corresponding to the selected co-ordinates of the position indicator.

63. In an apparatus for generating model data representative of a model in a three dimensional space from image data representative of a set of camera images

of an object;

an improvement wherein the apparatus comprises;

an interface comprising display means operable to display images to a user and input means responsive to user actuation;

control means operable to control the display means to display a model image based on an existing set of model data and to display one of the camera images of the object for selection by a user of an additional feature to be represented by additional model data;

receiving means for receiving an image point selection signal responsive to user actuation of the input means and identifying co-ordinates of an image point in the camera image defining the selected additional feature;

calculating means for calculating a locus in the three dimensional space defining positions of possible model points corresponding to the image point and consistent with the geometric relationship between the object and a camera position from which the displayed camera image was taken;

the control means being further operable to control the display means to display a position indicator in the model image at co-ordinates in the model image corresponding to one of the possible model points on the locus;

the apparatus further comprising means for receiving

positioning signals responsive to user actuation of the input means and updating the co-ordinates of the position indicator such that movement of the position indicator is constrained to follow a trajectory in the model image corresponding to the locus;

means for receiving a model point selecting signal responsive to user actuation of the input means and determining selected co-ordinates of the position indicator to be the position indicator co-ordinates at the time of receiving the model point selecting signal; and

means for determining co-ordinates of the additional model point in the three dimensional space corresponding to the selected co-ordinates of the position indicator.

64. In an apparatus for generating model data representative of a model in a three dimensional space from image data representative of a set of camera images of an object, a method wherein;

the apparatus performs the steps of;

displaying a model image based on an existing set of model data;

displaying one of the camera images of the object for selection by a user of an additional feature to be represented by additional model data;

receiving an image point selection signal responsive to user actuation of an input means and identifying co-

ordinates of an image point in the camera image defining the selected additional feature;

calculating a locus in the three dimensional space defining positions of possible model points corresponding to the image point and consistent with the geometric relationship between the object and a camera position from which the displayed camera image was taken;

displaying a position indicator in the model image at co-ordinates in the model image corresponding to one of the possible model points on the locus;

receiving positioning signals responsive to user actuation of the input means and updating the co-ordinates of the position indicator such that movement of the position indicator is constrained to follow a trajectory in the model image corresponding to the locus;

receiving a model point selecting signal responsive to user actuation of the input means and determining selected co-ordinates of the position indicator to be the position indicator co-ordinates at the time of receiving the model point selecting signal; and

determining co-ordinates of the additional model point in the three dimensional space corresponding to the selected co-ordinates of the position indicator.

65. In a method of operating an apparatus for generating model data defining a model in a three dimensional space, the model data comprising co-ordinates defining model

points and surface elements generated with reference to the model points; an improvement wherein the method comprises editing an existing set of model data by the steps of;

adding a new model point to the existing set of model data;

projecting the new model point onto the model and identifying a selected one of the surface elements onto which the new model point is projected;

identifying a subset of the model points which define the generation of the selected surface element;

adding the new model point to the subset to form an edited subset of model points; and

generating one or more edited surface elements from the edited subset of model points to replace the selected surface element.

66. In an apparatus for generating model data defining a model in a three dimensional space, the model data comprising co-ordinates defining model points and surface elements generated with reference to the model points, an improvement wherein the apparatus is operable to edit an existing set of model data and comprises;

means for adding a new model point to the existing set of model data;

means for projecting the new model point onto the model and identifying a selected one of the surface

elements onto which the new model point is projected;

means for identifying a subset of the model points which define the generation of the selected surface element;

means for adding the new model point to the subset to form an edited subset of model points; and

means for generating one or more edited surface elements from the edited subset of model points to replace the selected surface element.

67. In an apparatus for generating model data defining a model in a three dimensional space, the model data comprising co-ordinates defining model points and surface elements generated with reference to the model points; a method comprising editing an existing set of model data by the steps of;

adding a new model point to the existing set of model data;

projecting the new model point onto the model and identifying a selected one of the surface elements onto which the new model point is projected;

identifying a subset of the model points which define the generation of the selected surface element;

adding the new model point to the subset to form an edited subset of model points; and

generating one or more edited surface elements from the edited subset of model points to replace the selected surface element

surface element.

69. In a method of operating an apparatus for generating model data representative of a three dimensional model of an object from input signals representative of a set of camera images of the object taken from a plurality of camera positions, an improvement wherein the method comprises;

displaying a set of icons, each being associated with a respective one of the camera images of the object;

receiving a selection signal responsive to user actuation of an input means whereby the selection signal identifies a selected one of the icons;

determining a selected camera image from the set of camera images corresponding to the selected icon;

displaying the selected image;

determining position data representative of a selected camera position from which the selected image was taken;

generating in accordance with said model a model image representative of a view of the model from a viewpoint corresponding to the position data; and

displaying the model image for visual comparison with the selected image by the user.

70. In an apparatus for generating model data representative of a three dimensional model of an object

from input signals representative of a set of camera images of the object taken from a plurality of camera positions, an improvement wherein the apparatus comprises;

display means for displaying a set of icons, each being associated with a respective one of the camera images of the object;

means for receiving a selection signal responsive to user actuation of an input means whereby the selection signal identifies a selected one of the icons;

means for determining a selected camera image from the set of camera images corresponding to the selected icon whereby the display means is operable to display the selected image;

means for determining position data representative of a selected camera position from which the selected image was taken;

means for generating in accordance with said model a model image representative of a view of the model from a viewpoint corresponding to the position data; and control means for controlling the display means to display the model image for visual comparison with the selected image by the user.

71. In an apparatus for generating model data representative of a three dimensional model of an object from input signals representative of a set of camera

images of the object taken from a plurality of camera positions, a method comprising;

displaying a set of icons, each being associated with a respective one of the camera images of the object;

receiving a selection signal responsive to user actuation of an input means whereby the selection signal identifies a selected one of the icons;

determining a selected camera image from the set of camera images corresponding to the selected icon;

displaying the selected image;

determining position data representative of a selected camera position from which the selected image was taken;

generating in accordance with said model a model image representative of a view of the model from a viewpoint corresponding to the position data; and

displaying the model image for visual comparison with the selected image by the user.

ABSTRACT

METHOD AND APPARATUS FOR GENERATING MODEL DATA FROM CAMERA IMAGES

A three-dimensional model of an object is generated from image data representing a set of camera images of the object. Refinement of the model is carried out on the basis of a comparison of a displayed model image and a displayed camera image, enabling a user to select co-ordinates in the camera image defining the selection of an additional feature which is to be added to the model. The model calculates a locus in the three-dimensional space defining positions of possible model points corresponding to the selected image point and consistent with the geometric relationship between the object and a camera position from which the displayed camera image was taken. A position indicator is displayed in the model image at co-ordinates on the locus and the position indicator is moveable by the user in a manner which is constrained to follow a trajectory in the model image corresponding to the locus. The user may then select a required position of the new model point on the locus and

the model data is updated to include the new model point corresponding to such selection. The surface of the model may be edited to incorporate a new model point by identifying a facet by projection onto the model and automatically re-facetting the model. Evaluation of the model image requires presenting corresponding camera and model images, the model viewpoint being determined automatically by user selection of camera frames or camera position.

(Figures 5 and 7 refer)

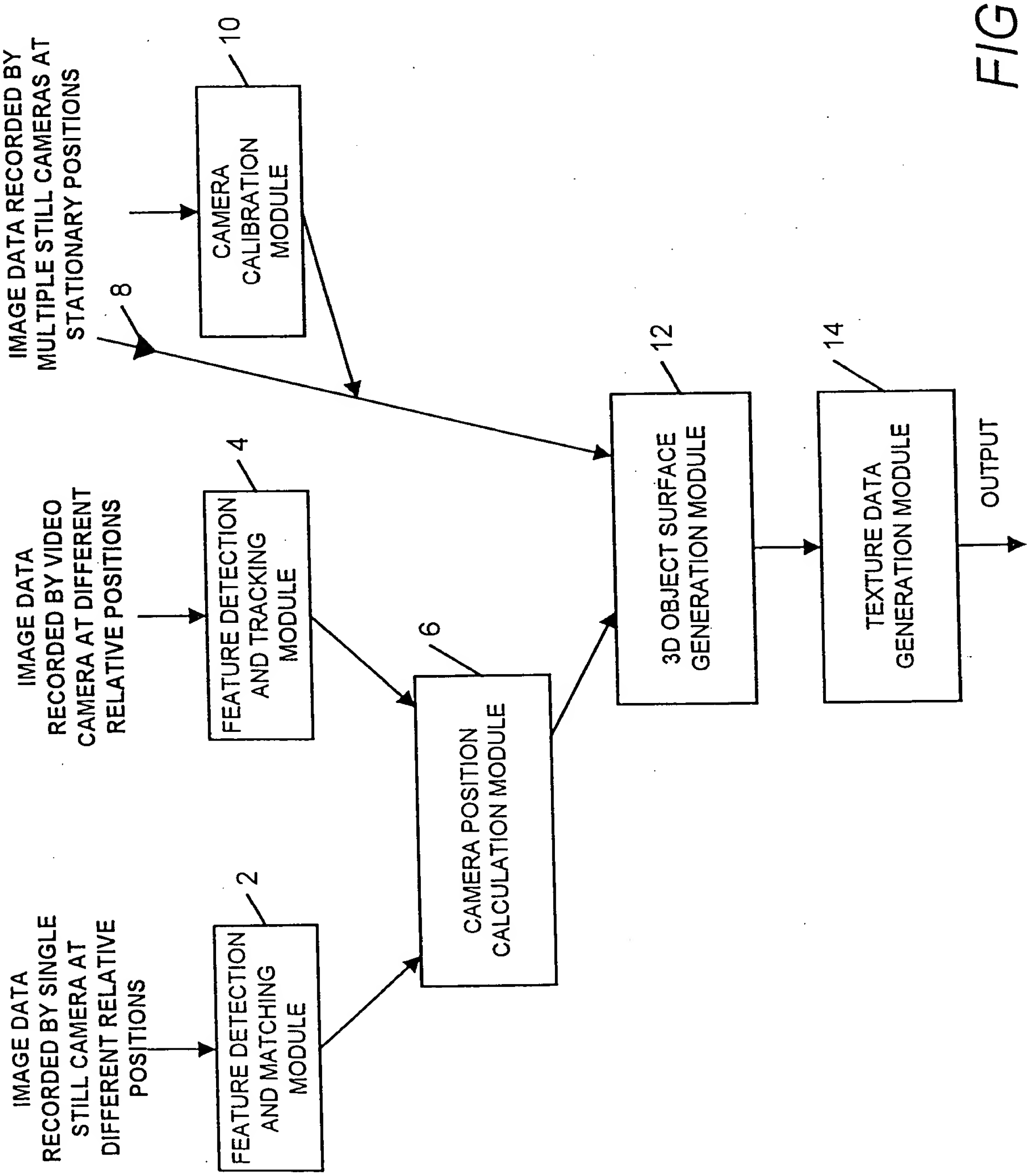
IMAGE DATA RECORDED BY SINGLE STILL CAMERA AT DIFFERENT RELATIVE POSITIONS
FEATURE DETECTION AND MATCHING MODULE
2
IMAGE DATA RECORDED BY VIDEO CAMERA AT DIFFERENT RELATIVE POSITIONS
FEATURE DETECTION AND TRACKING MODULE
4
CAMERA POSITION CALCULATION MODULE
6
IMAGE DATA RECORDED BY MULTIPLE STILL CAMERAS AT STATIONARY POSITIONS
8
CAMERA CALIBRATION MODULE
10
3D OBJECT SURFACE GENERATION MODULE
12
TEXTURE DATA GENERATION MODULE
14
OUTPUT

FIG. 1

Fig 2

MODEL WINDOW SHOWS FEATURE MISSING FROM MODEL IMAGE WHEN COMPARED WITH CAMERA IMAGE

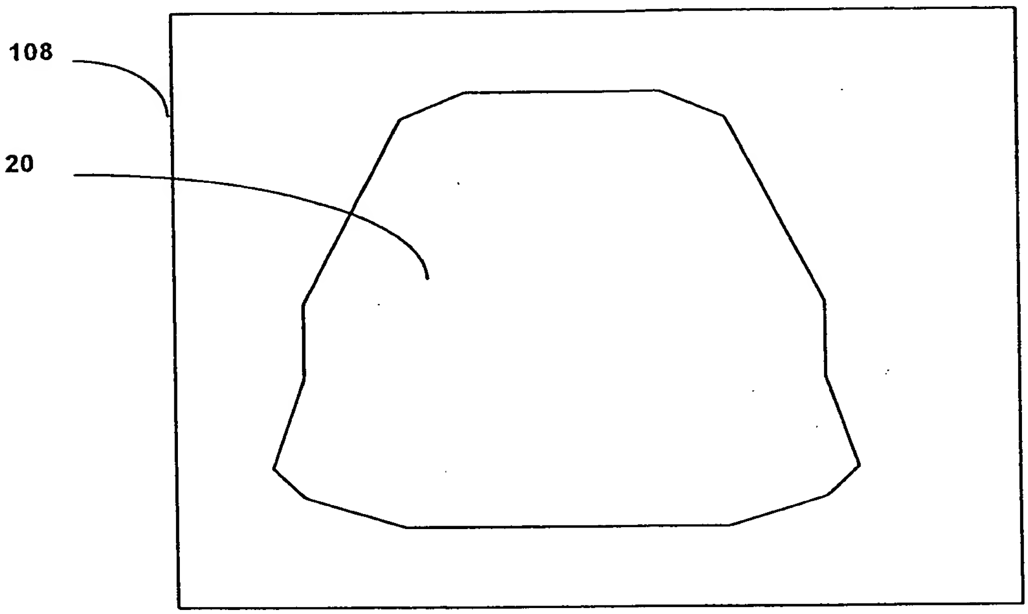

Fig 3

IN CAMERA IMAGE WINDOW ,USER SELECTS NEW IMAGE POINT FOR ADDITION TO MODEL

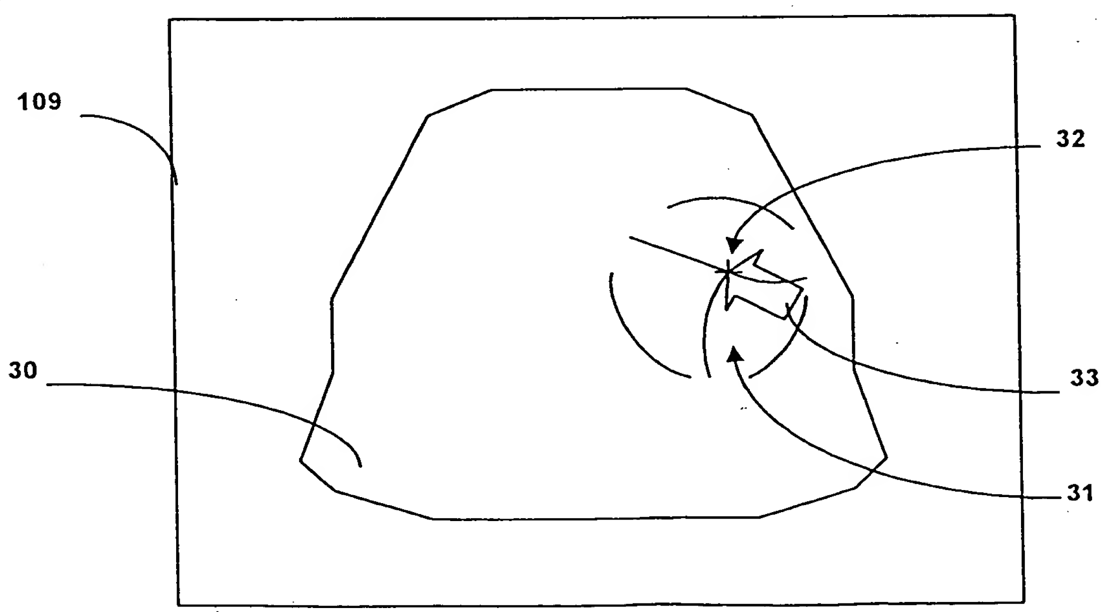

Fig 4

MODEL CALCULATES LOCUS OF NEW MODEL POINT

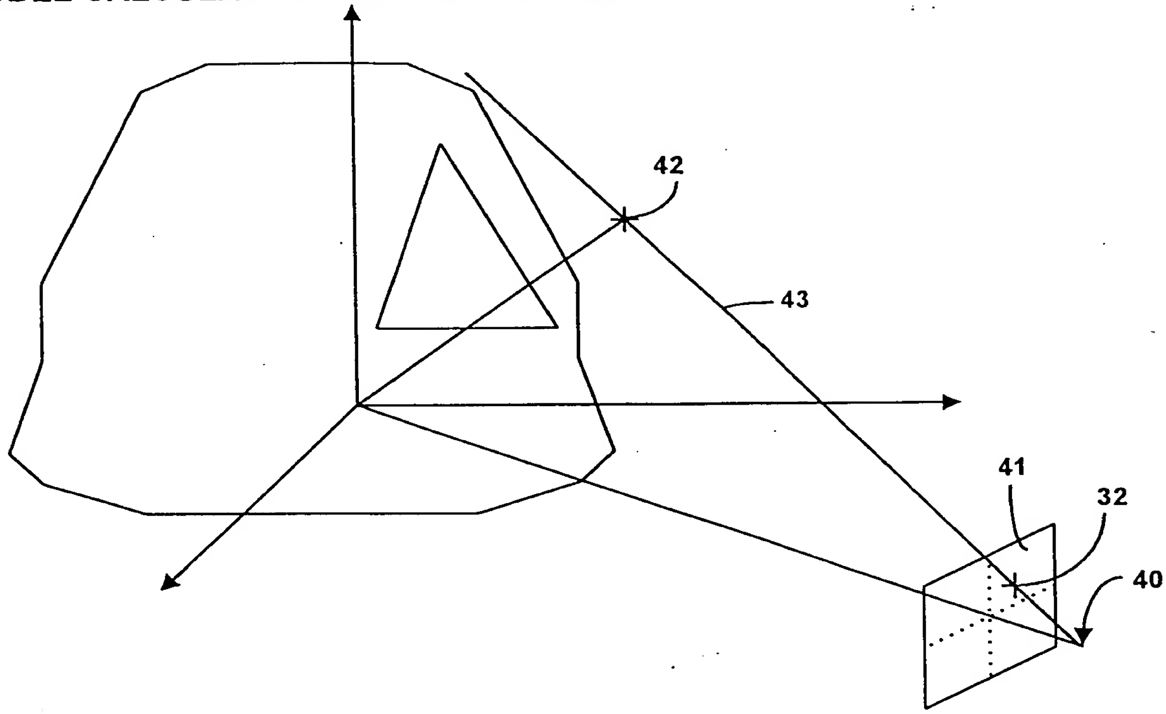

Fig 5

IN MODEL WINDOW,MODEL IMAGE IS DISPLAYED FROM A DIFFERENT VIEWING ANGLE AND USER MOVES NEW MODEL POINT TO REQUIRED POSITION ,CONSTRAINED BY CALCULATED LOCUS

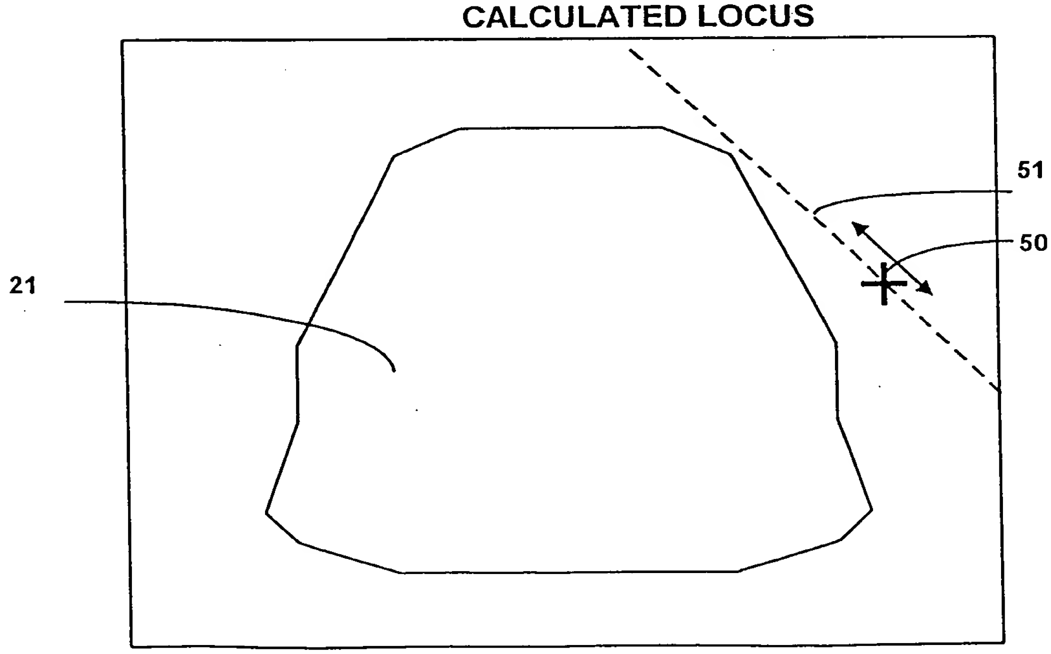

Fig 6

IN MODEL WINDOW, USER SELECTS EXISTING MODEL POINTS FOR CONNECTION TO NEW POINT

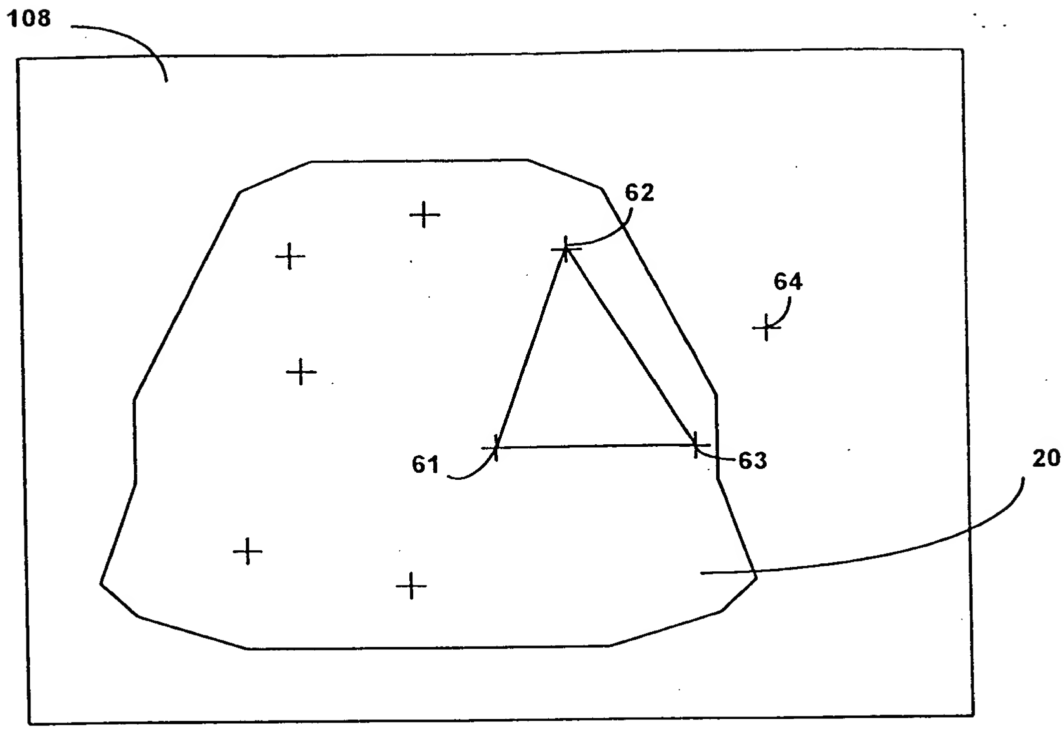

Fig 7

IN MODEL WINDOW, MODEL IMAGE NOW SHOWS NEW MODEL POINT AND FACETS

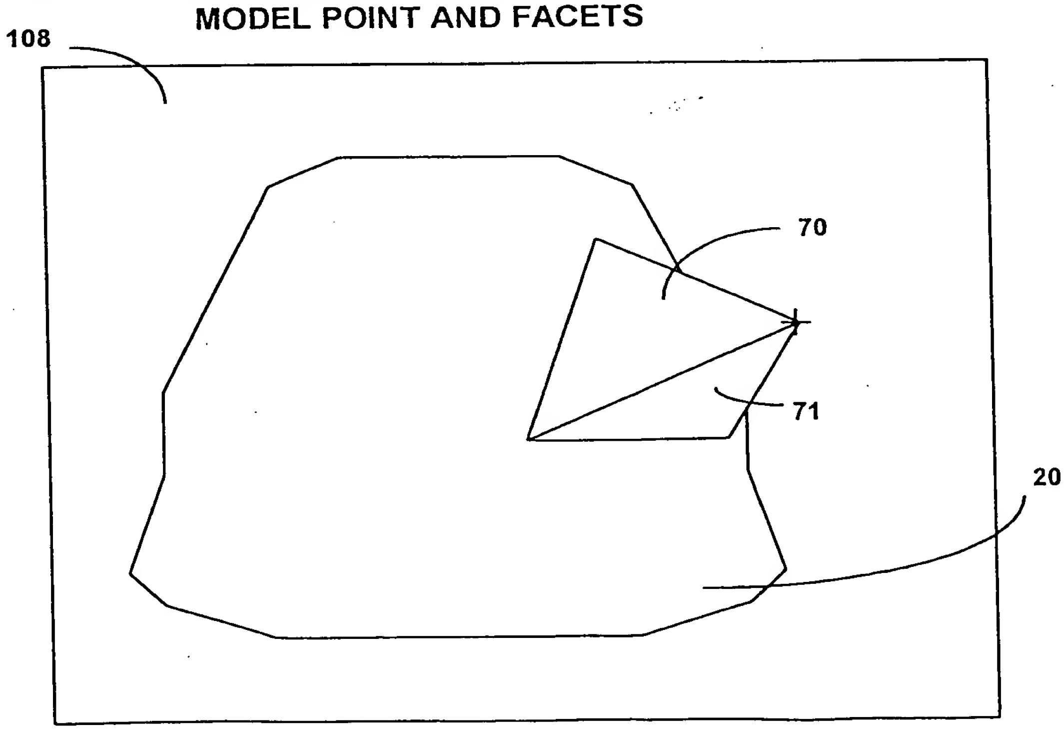

Fig 8

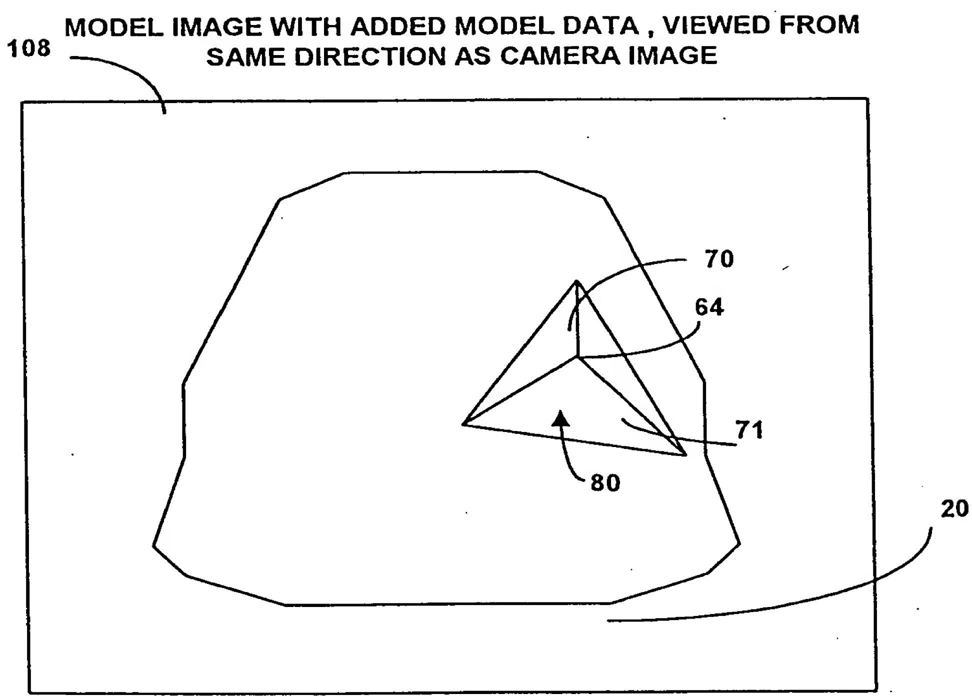
MODEL IMAGE WITH ADDED MODEL DATA , VIEWED FROM SAME DIRECTION AS CAMERA IMAGE
108
70
64
71
80
20

FIG. 9

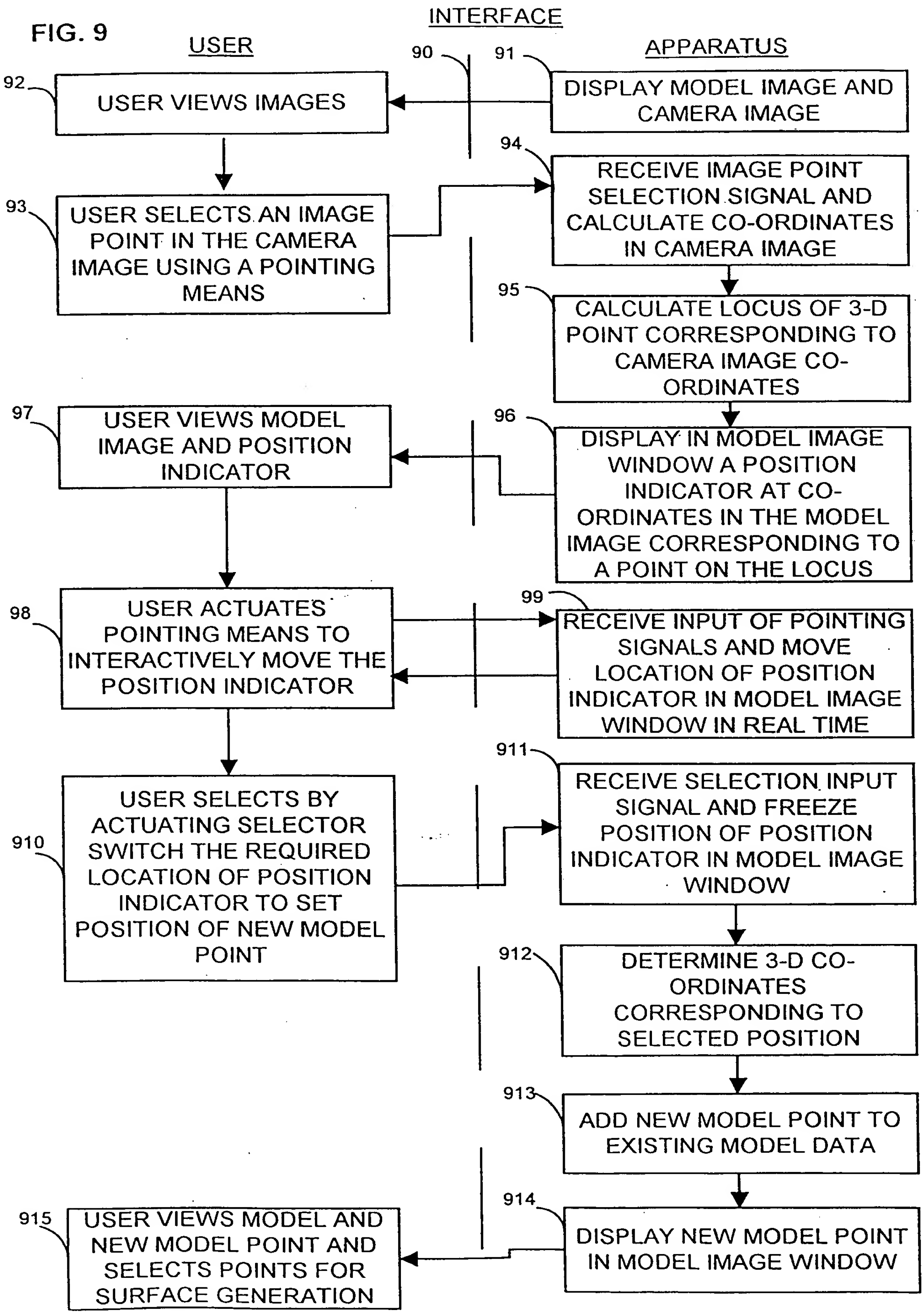
INTERFACE
USER
APPARATUS
90
91
92
USER VIEWS IMAGES
DISPLAY MODEL IMAGE AND CAMERA IMAGE
93
USER SELECTS AN IMAGE POINT IN THE CAMERA IMAGE USING A POINTING MEANS
94
RECEIVE IMAGE POINT SELECTION SIGNAL AND CALCULATE CO-ORDINATES IN CAMERA IMAGE
95
CALCULATE LOCUS OF 3-D POINT CORRESPONDING TO CAMERA IMAGE CO-ORDINATES
97
USER VIEWS MODEL IMAGE AND POSITION INDICATOR
96
DISPLAY IN MODEL IMAGE WINDOW A POSITION INDICATOR AT CO-ORDINATES IN THE MODEL IMAGE CORRESPONDING TO A POINT ON THE LOCUS
98
USER ACTUATES POINTING MEANS TO INTERACTIVELY MOVE THE POSITION INDICATOR
99
RECEIVE INPUT OF POINTING SIGNALS AND MOVE LOCATION OF POSITION INDICATOR IN MODEL IMAGE WINDOW IN REAL TIME
910
USER SELECTS BY ACTUATING SELECTOR SWITCH THE REQUIRED LOCATION OF POSITION INDICATOR TO SET POSITION OF NEW MODEL POINT
911
RECEIVE SELECTION INPUT SIGNAL AND FREEZE POSITION OF POSITION INDICATOR IN MODEL IMAGE WINDOW
912
DETERMINE 3-D CO-ORDINATES CORRESPONDING TO SELECTED POSITION
913
ADD NEW MODEL POINT TO EXISTING MODEL DATA
914
DISPLAY NEW MODEL POINT IN MODEL IMAGE WINDOW
915
USER VIEWS MODEL AND NEW MODEL POINT AND SELECTS POINTS FOR SURFACE GENERATION

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Fig 10

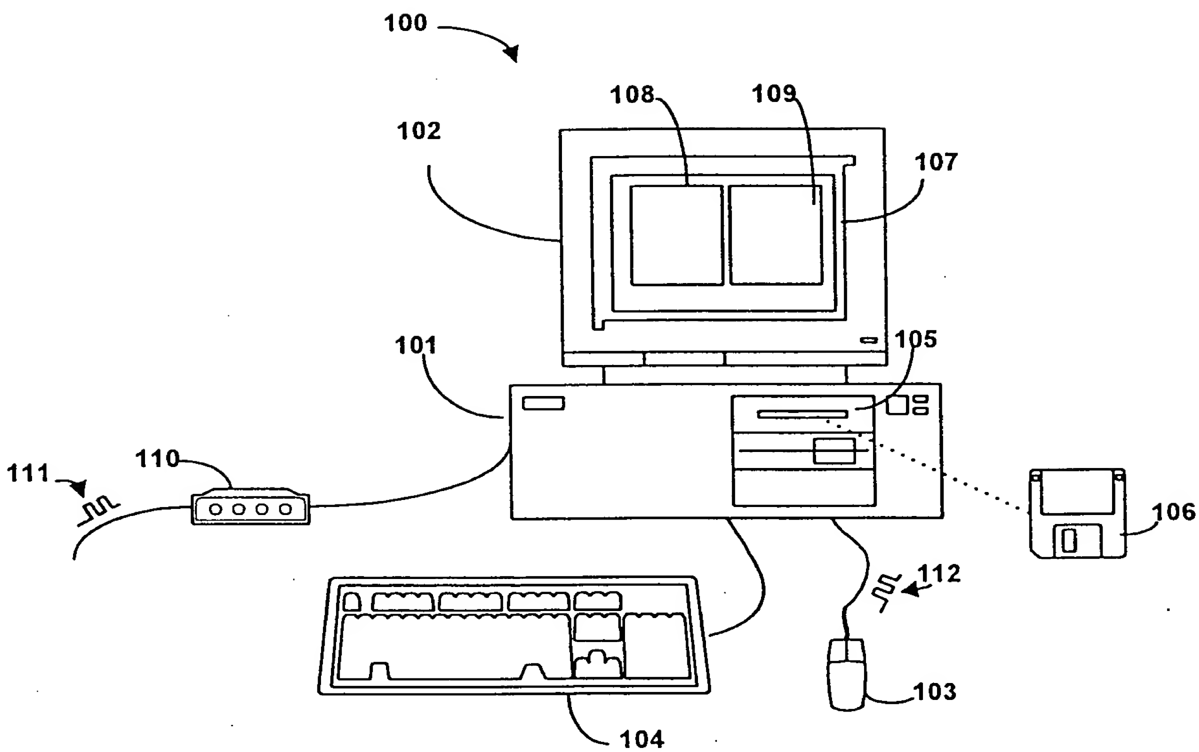

Fig 11

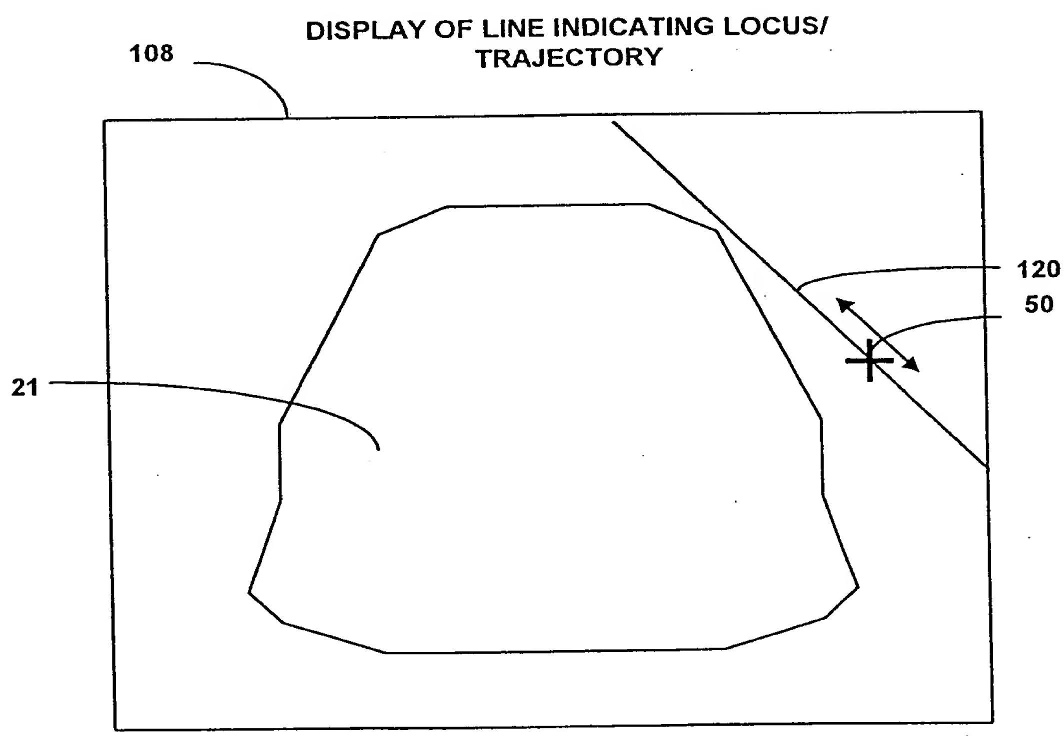

Fig 12

ADDING A NEW MODEL POINT

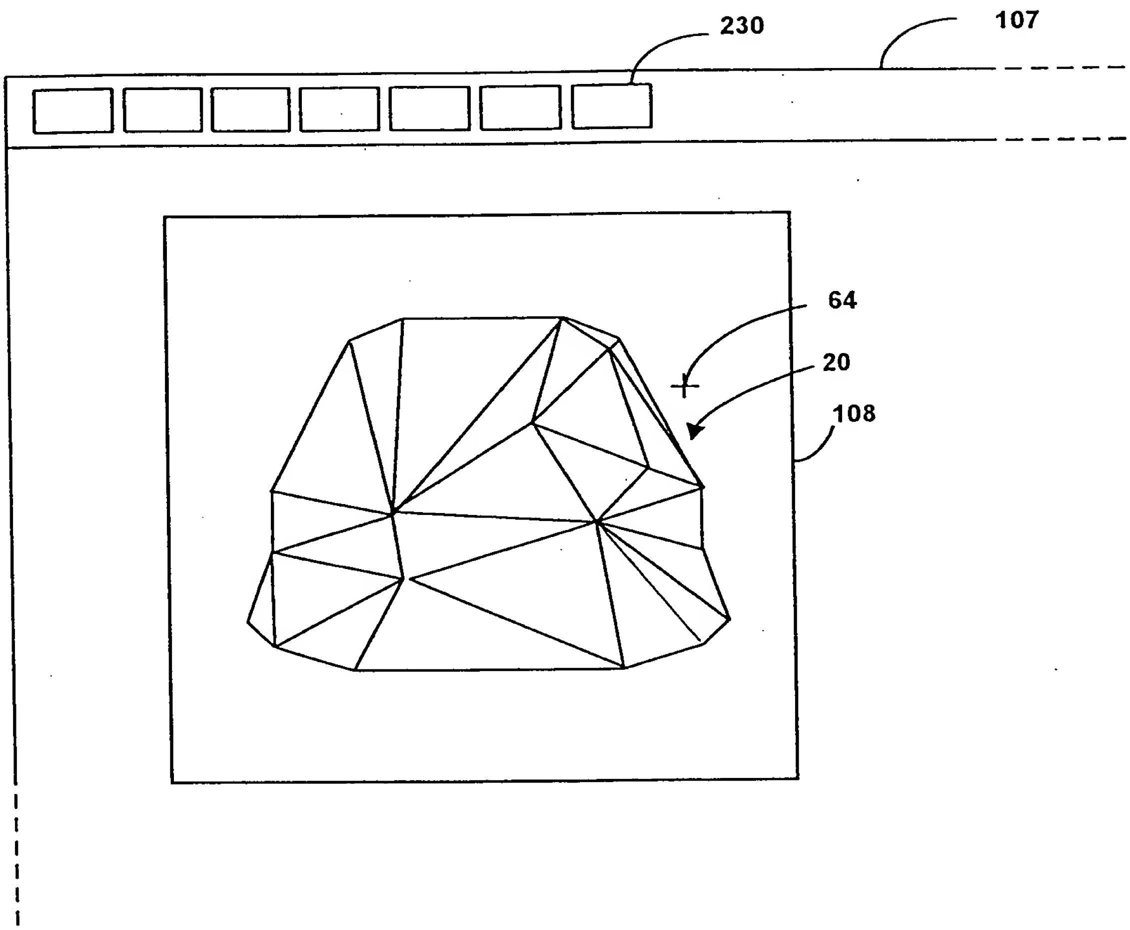

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Fig 13A

CAMERA SELECTION WINDOW WITH CAMERA ICONS

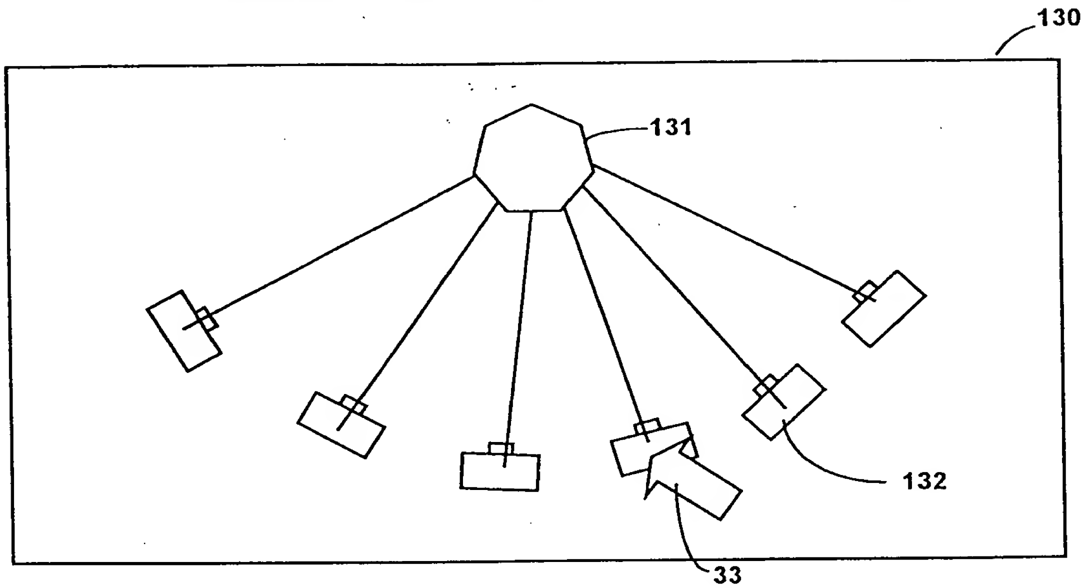

Fig 13B

CAMERA SELECTION WINDOW WITH CAMERA IMAGES

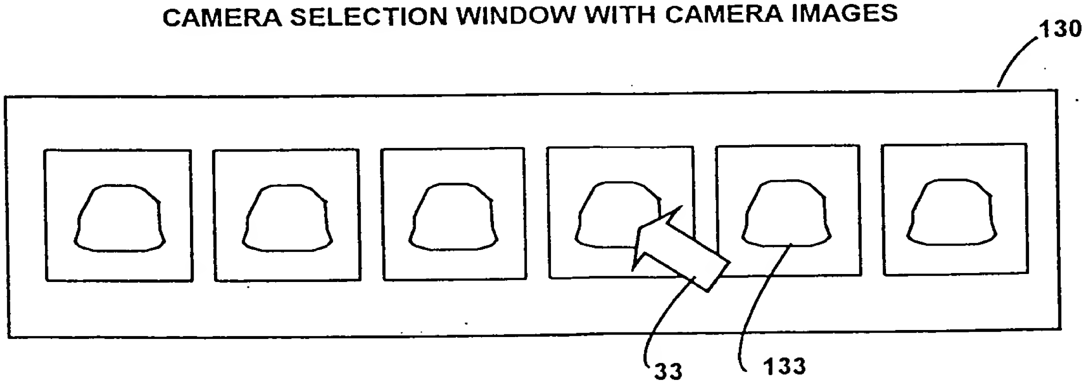

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Fig 14

CALCULATE FACET INTERSECTED BY RAY THROUGH CAMERA POSITION AND ADDED MODEL POINT

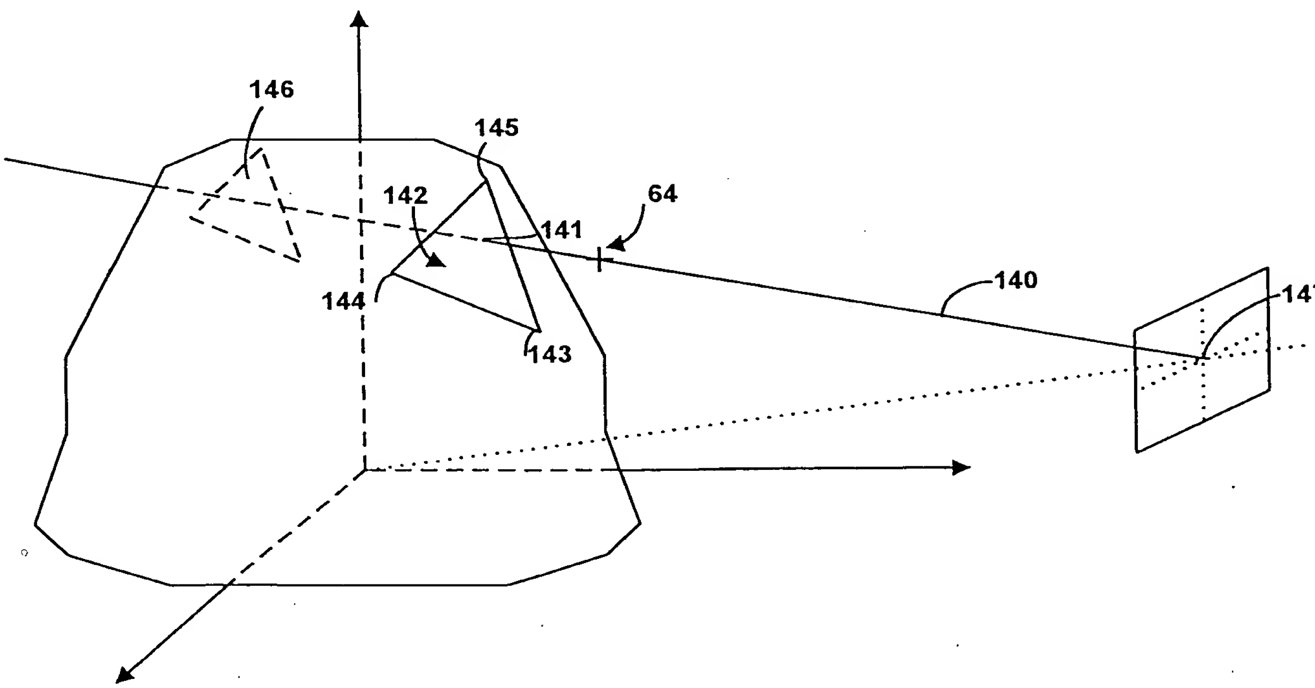

Fig 15

SUBDIVIDE FACET TO INCLUDE ADDED MODEL POINT

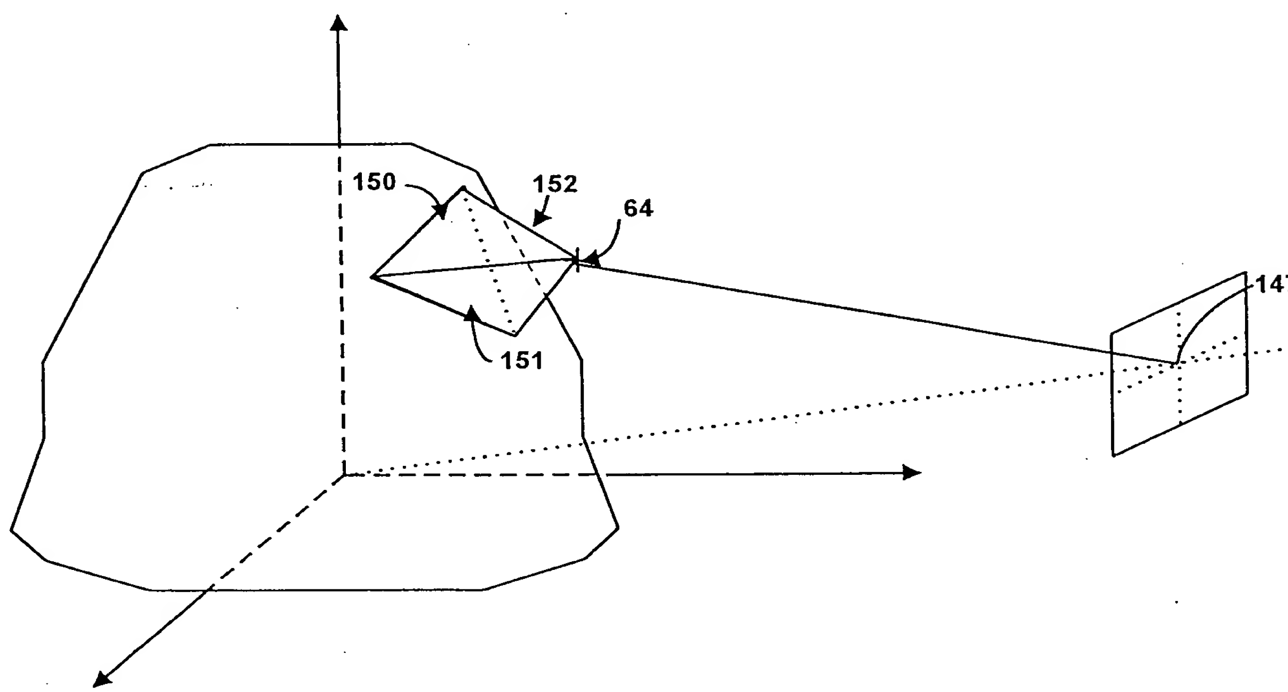

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Fig 16

DISPLAY NEW MODEL INCLUDING ADDED POINT AND NEW FACETS

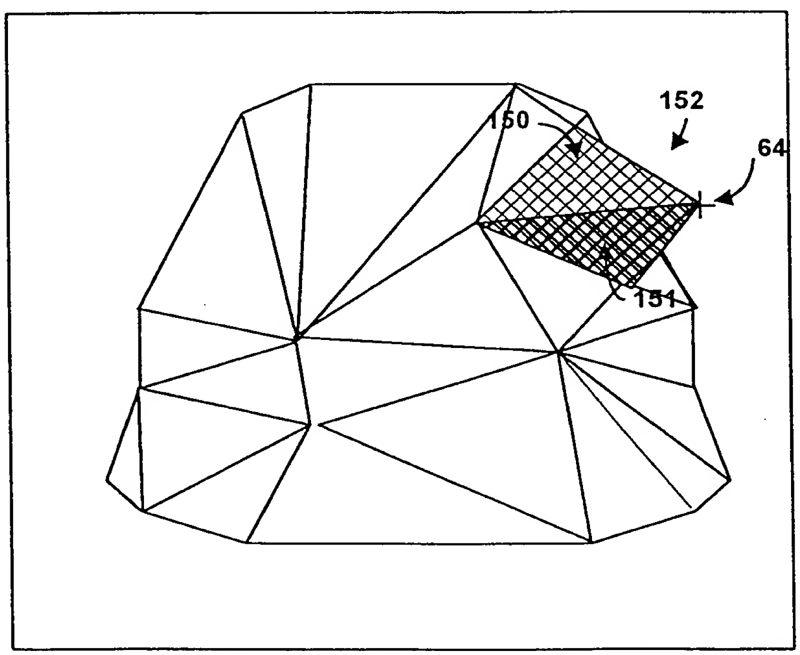

FIG. 17

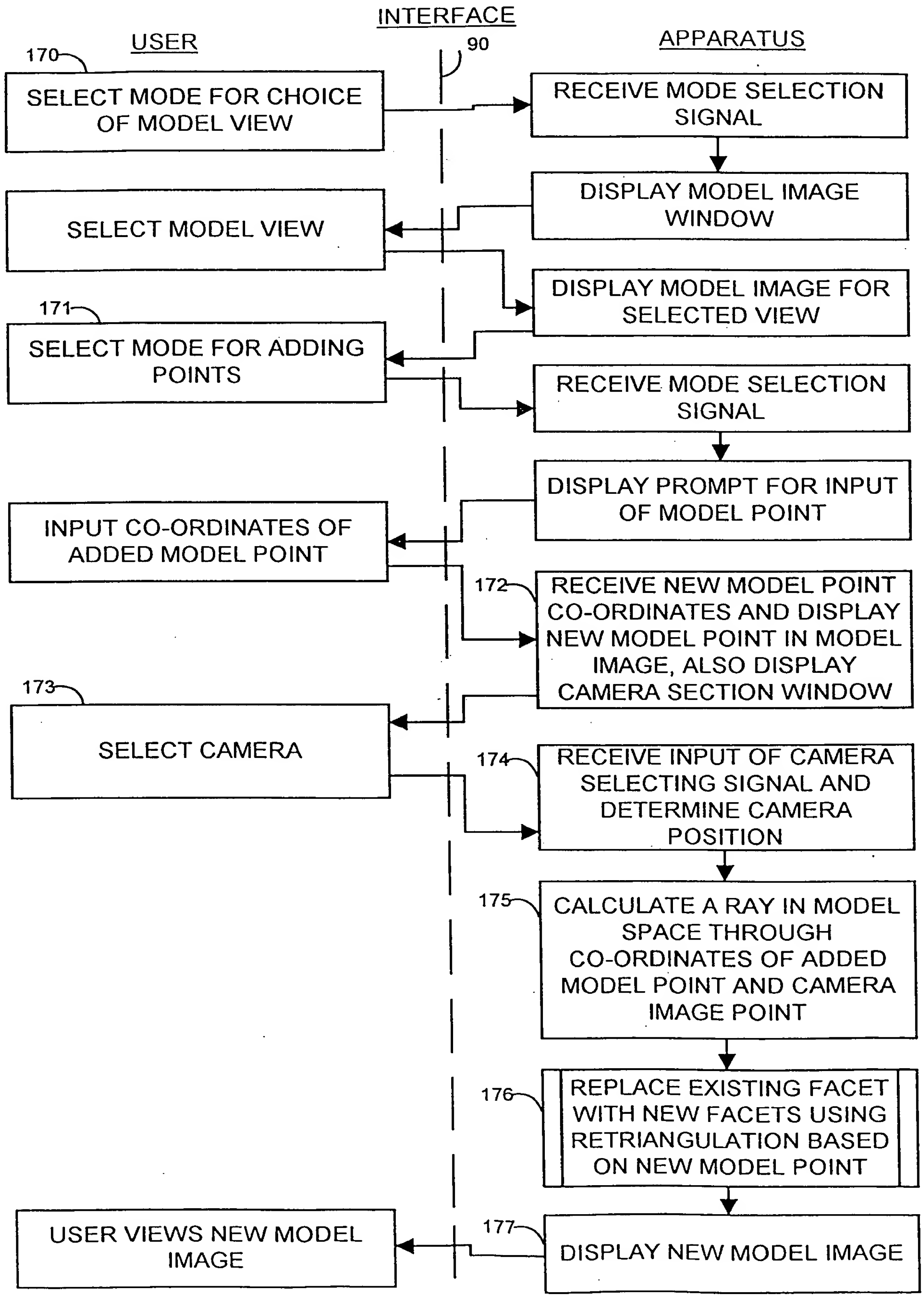
INTERFACE
USER
APPARATUS
170
90
SELECT MODE FOR CHOICE OF MODEL VIEW
RECEIVE MODE SELECTION SIGNAL
DISPLAY MODEL IMAGE WINDOW
SELECT MODEL VIEW
DISPLAY MODEL IMAGE FOR SELECTED VIEW
171
SELECT MODE FOR ADDING POINTS
RECEIVE MODE SELECTION SIGNAL
DISPLAY PROMPT FOR INPUT OF MODEL POINT
INPUT CO-ORDINATES OF ADDED MODEL POINT
172
RECEIVE NEW MODEL POINT CO-ORDINATES AND DISPLAY NEW MODEL POINT IN MODEL IMAGE, ALSO DISPLAY CAMERA SECTION WINDOW
173
SELECT CAMERA
174
RECEIVE INPUT OF CAMERA SELECTING SIGNAL AND DETERMINE CAMERA POSITION
175
CALCULATE A RAY IN MODEL SPACE THROUGH CO-ORDINATES OF ADDED MODEL POINT AND CAMERA IMAGE POINT
176
REPLACE EXISTING FACET WITH NEW FACETS USING RETRIANGULATION BASED ON NEW MODEL POINT
177
USER VIEWS NEW MODEL IMAGE
DISPLAY NEW MODEL IMAGE

FIG. 18

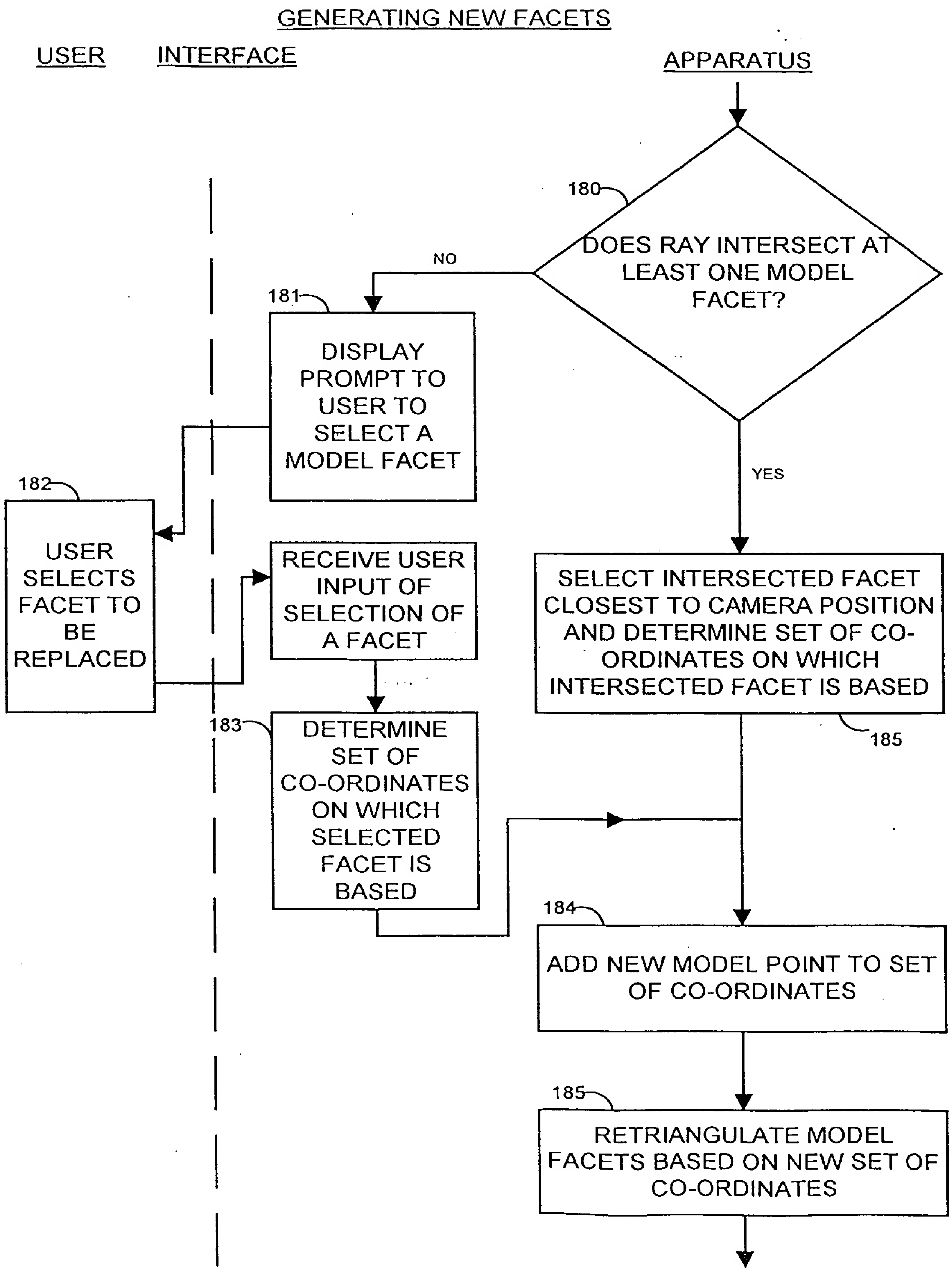
GENERATING NEW FACETS
USER
INTERFACE
APPARATUS
180
DOES RAY INTERSECT AT LEAST ONE MODEL FACET?
NO
YES
181
DISPLAY PROMPT TO USER TO SELECT A MODEL FACET
182
USER SELECTS FACET TO BE REPLACED
RECEIVE USER INPUT OF SELECTION OF A FACET
183
DETERMINE SET OF CO-ORDINATES ON WHICH SELECTED FACET IS BASED
SELECT INTERSECTED FACET CLOSEST TO CAMERA POSITION AND DETERMINE SET OF CO-ORDINATES ON WHICH INTERSECTED FACET IS BASED
185
184
ADD NEW MODEL POINT TO SET OF CO-ORDINATES
185
RETRIANGULATE MODEL FACETS BASED ON NEW SET OF CO-ORDINATES

Fig 19

IDENTIFY COORDINATES IN CAMERA IMAGE OF FEATURE CORRESPONDING TO ADDED MODEL POINT

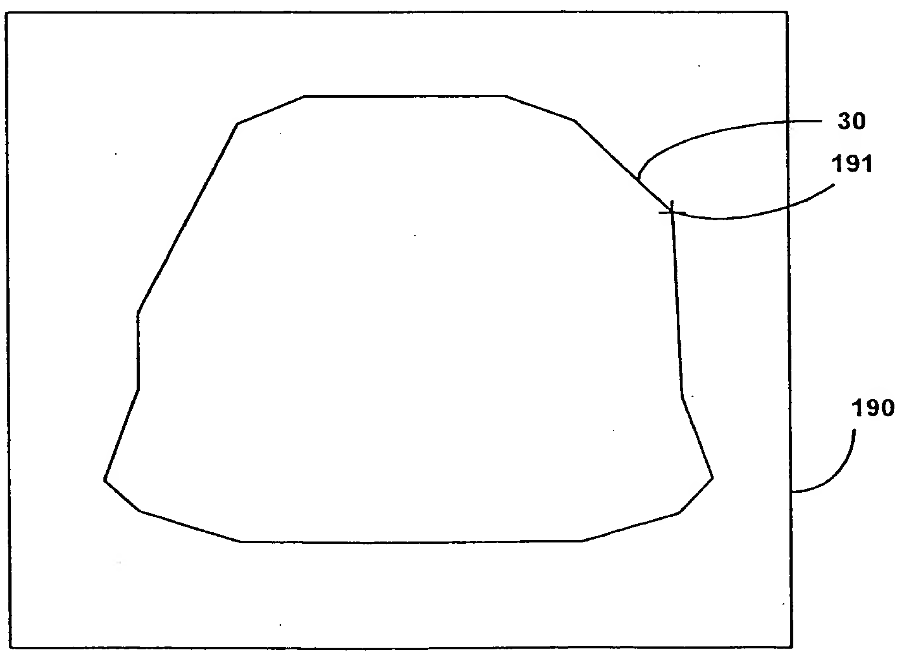

Fig 20

CALCULATE FACET INTERSECTED BY RAY THROUGH CAMERA IMAGE POINT AND ADDED MODEL POINT

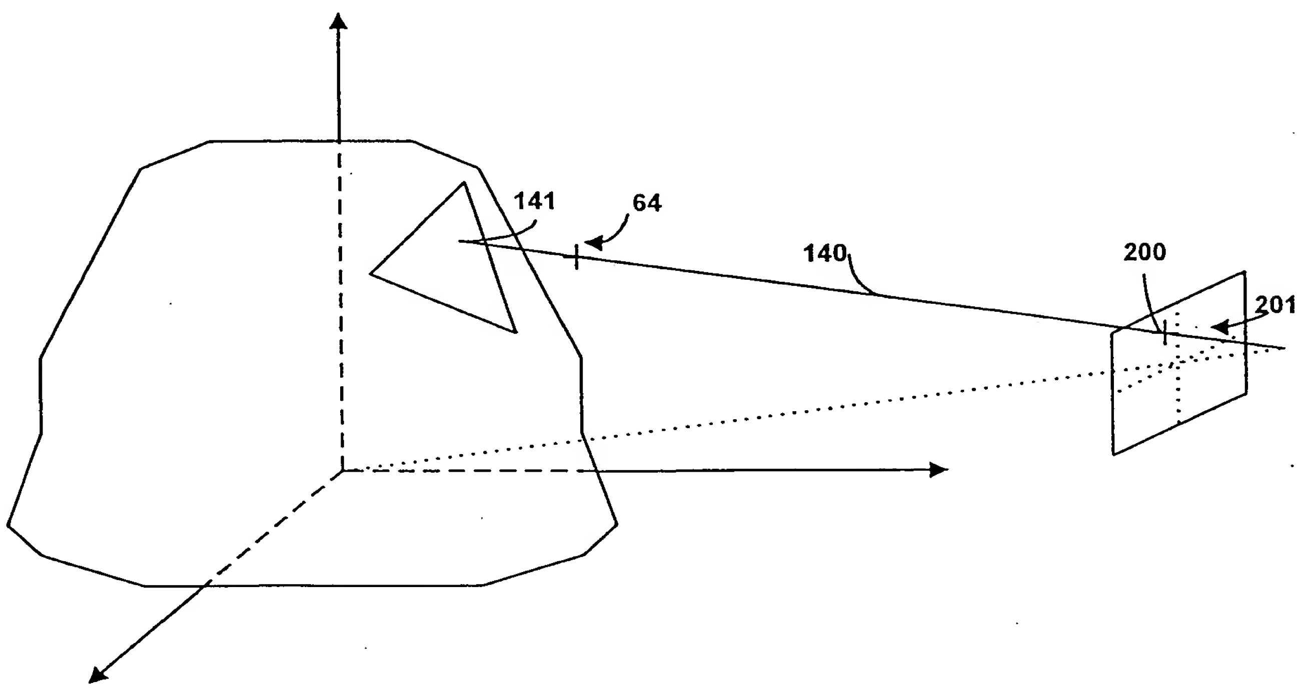

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FIG. 21

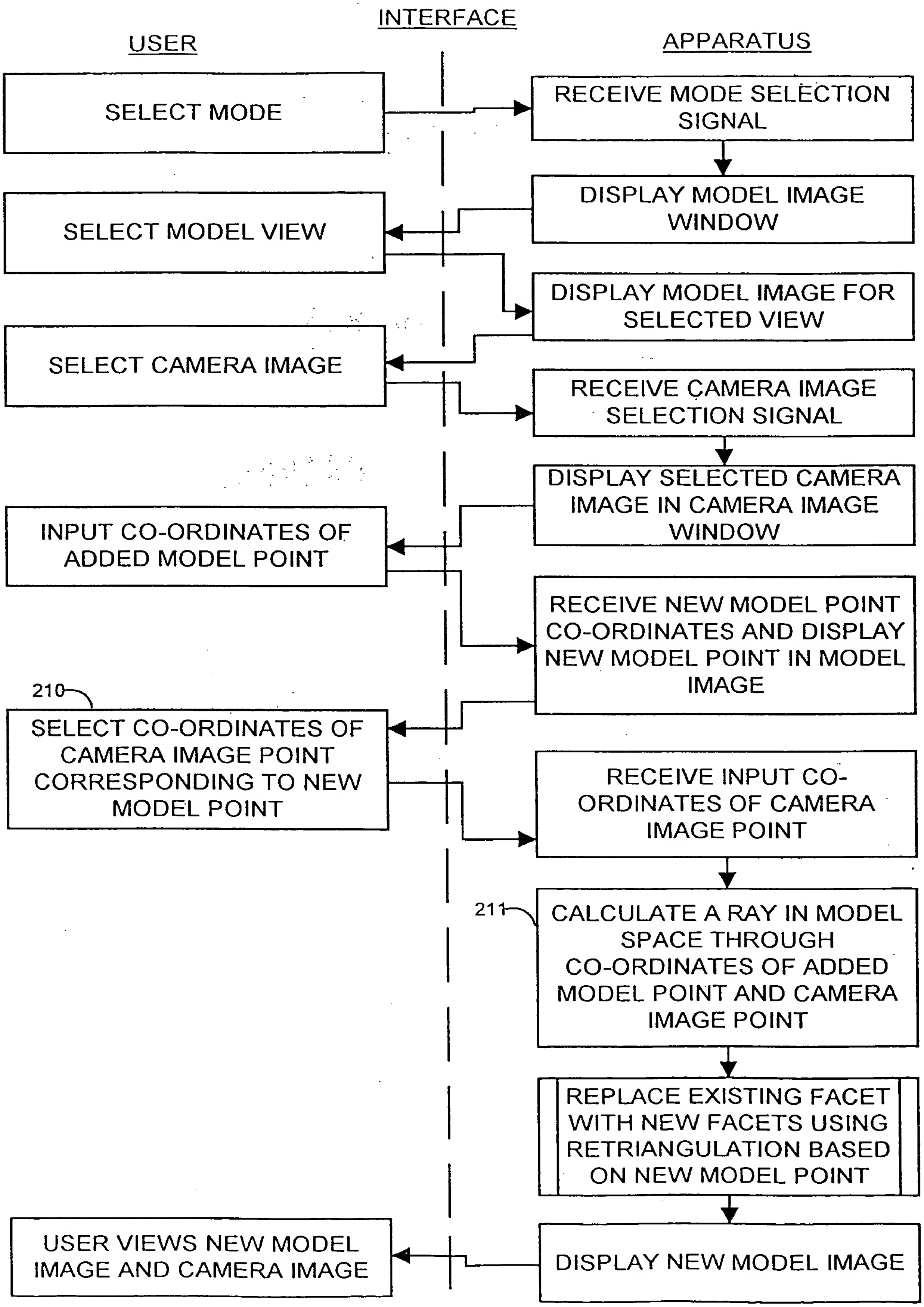

Fig 22

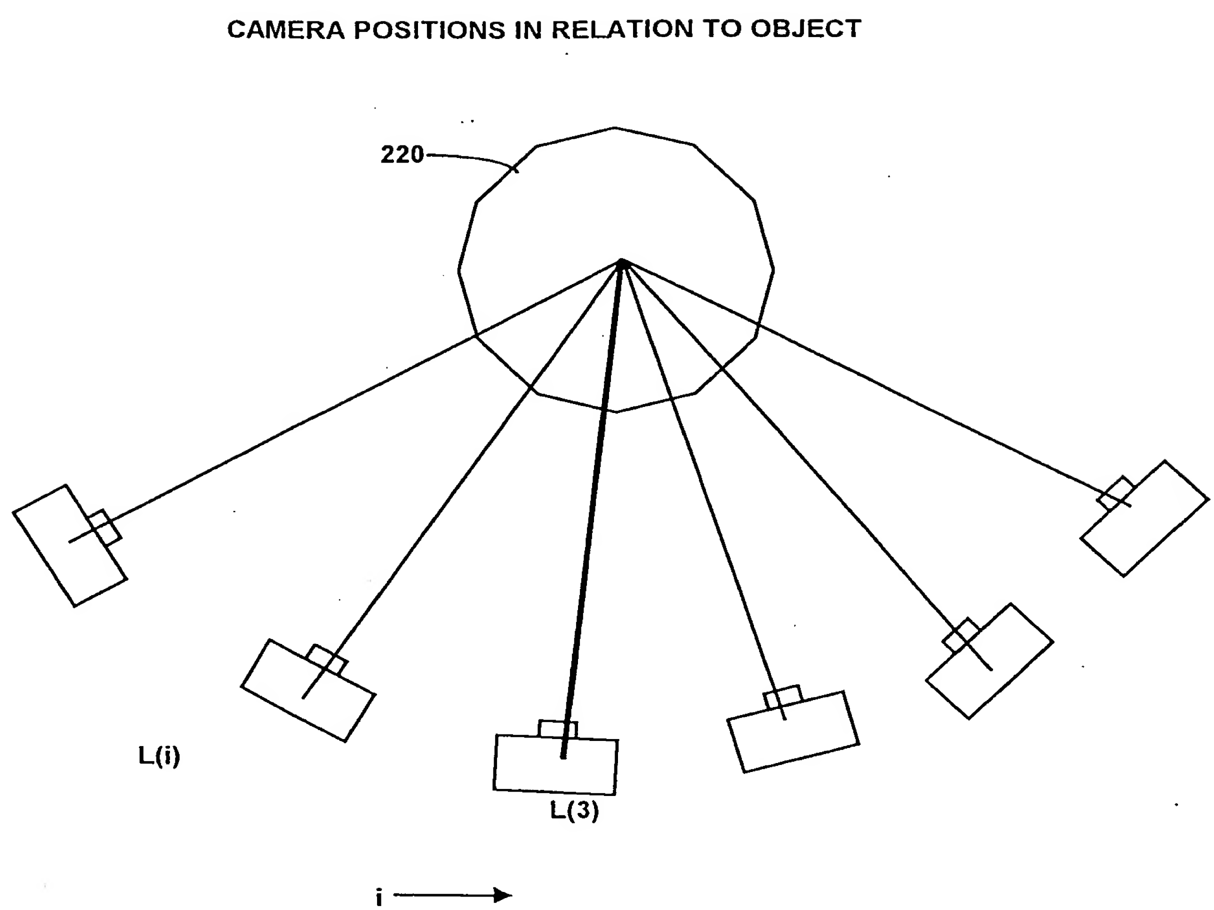

Fig 23

IMAGE SELECTION USING THUMBNAIL CAMERA IMAGE ICONS

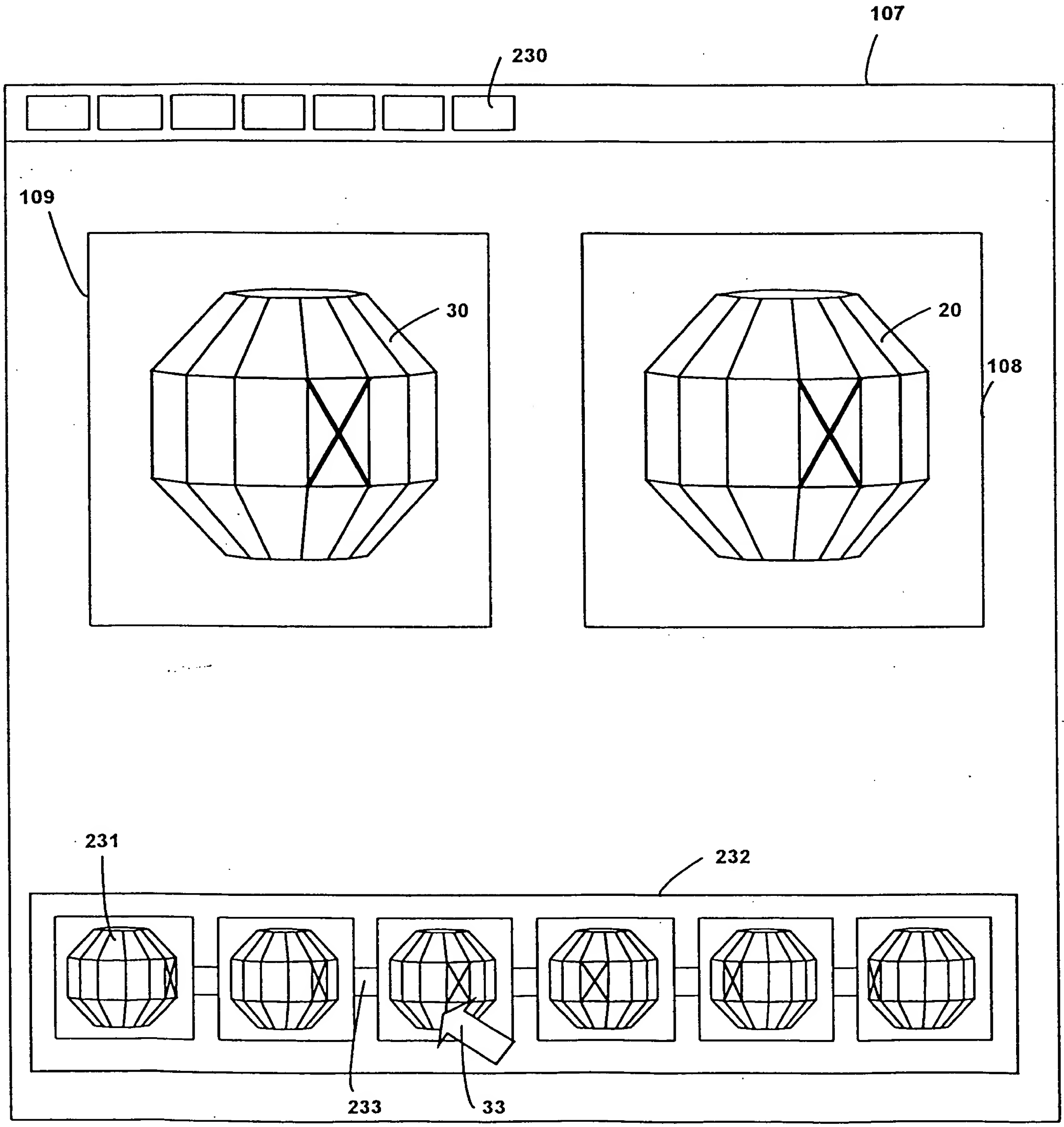

FIG.24

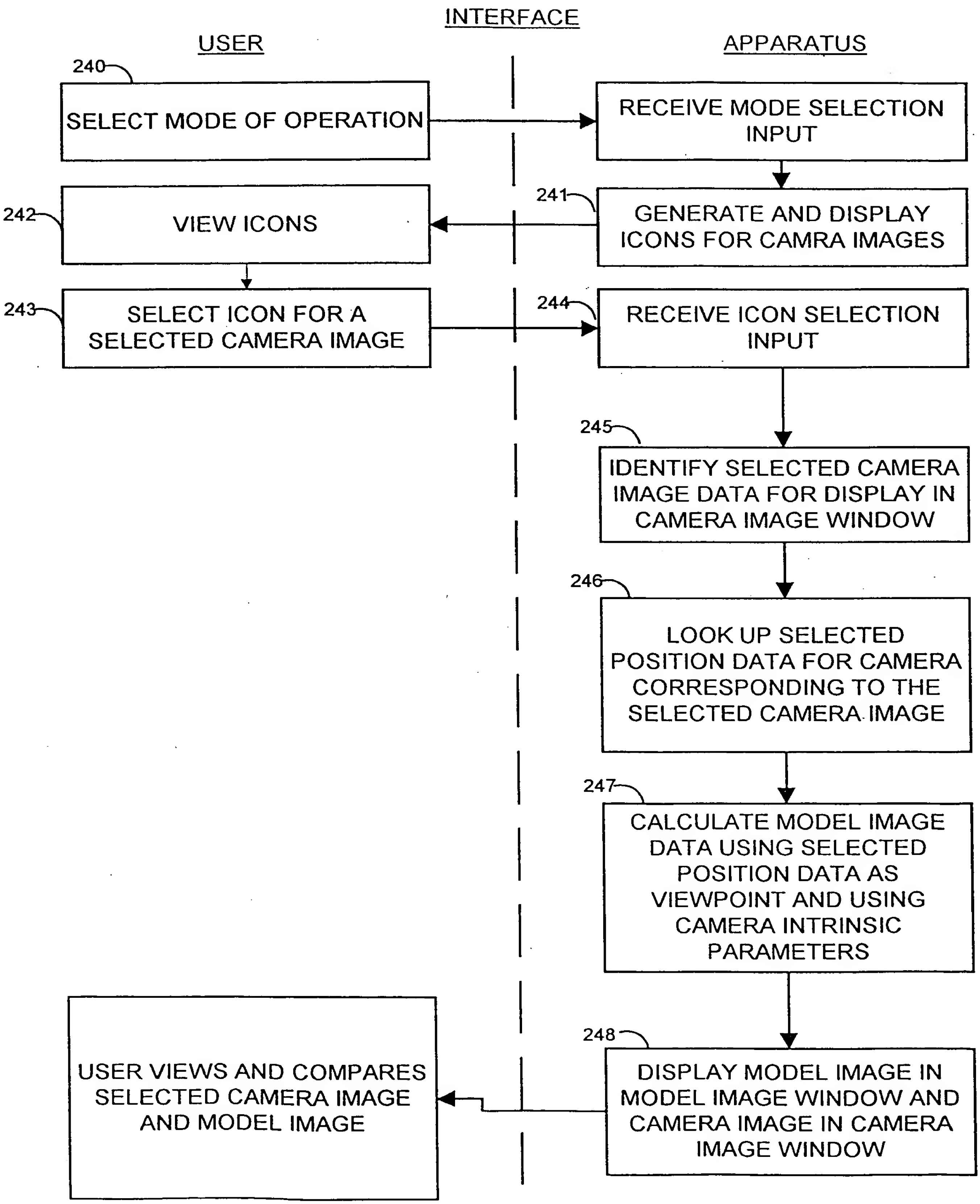
INTERFACE
USER
APPARATUS
240
SELECT MODE OF OPERATION
RECEIVE MODE SELECTION INPUT
241
242
VIEW ICONS
GENERATE AND DISPLAY ICONS FOR CAMRA IMAGES
243
SELECT ICON FOR A SELECTED CAMERA IMAGE
244
RECEIVE ICON SELECTION INPUT
245
IDENTIFY SELECTED CAMERA IMAGE DATA FOR DISPLAY IN CAMERA IMAGE WINDOW
246
LOOK UP SELECTED POSITION DATA FOR CAMERA CORRESPONDING TO THE SELECTED CAMERA IMAGE
247
CALCULATE MODEL IMAGE DATA USING SELECTED POSITION DATA AS VIEWPOINT AND USING CAMERA INTRINSIC PARAMETERS
248
DISPLAY MODEL IMAGE IN MODEL IMAGE WINDOW AND CAMERA IMAGE IN CAMERA IMAGE WINDOW
USER VIEWS AND COMPARES SELECTED CAMERA IMAGE AND MODEL IMAGE

Fig 25

IMAGE SELECTION USING CAMERA POSITION ICONS

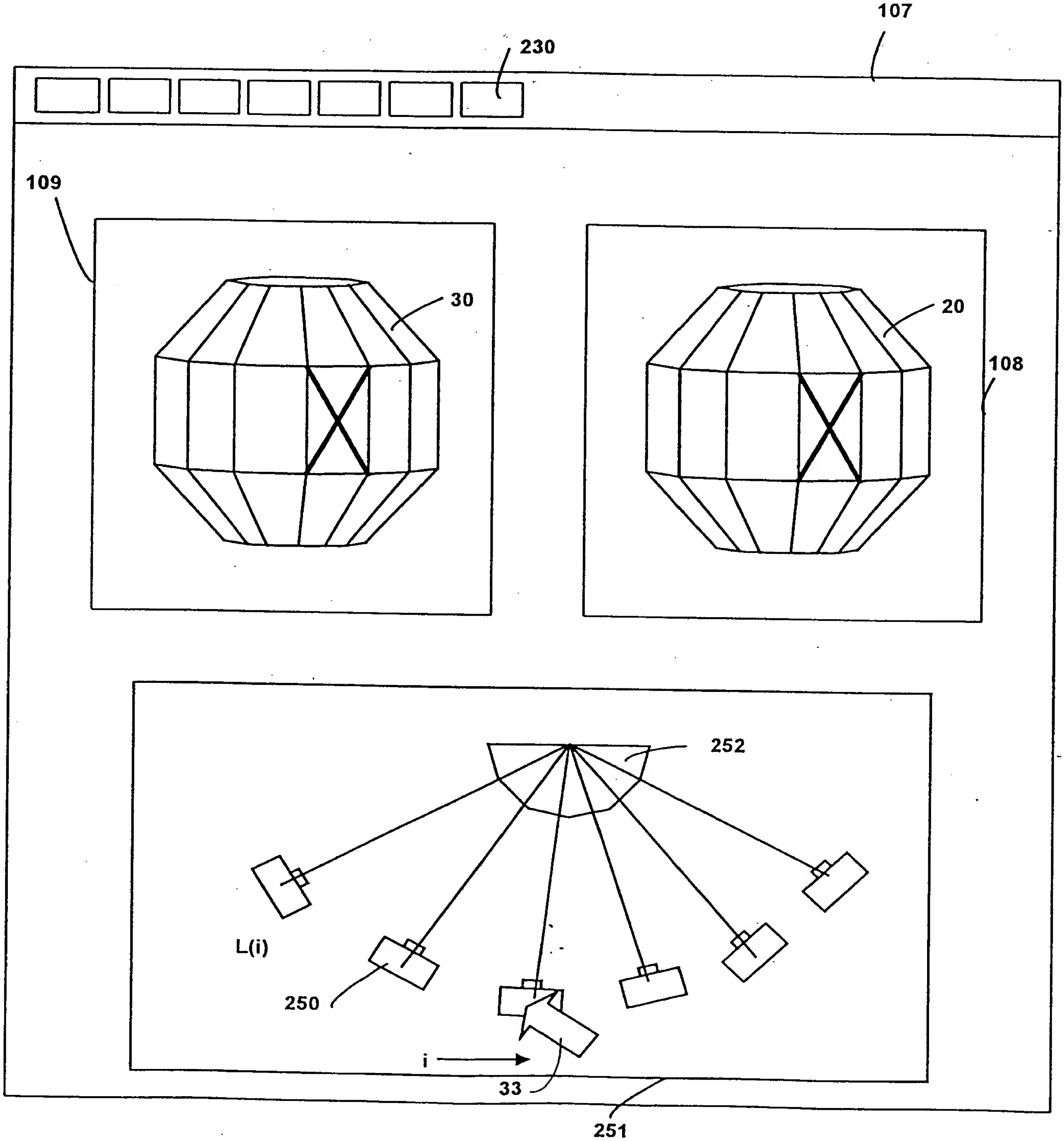

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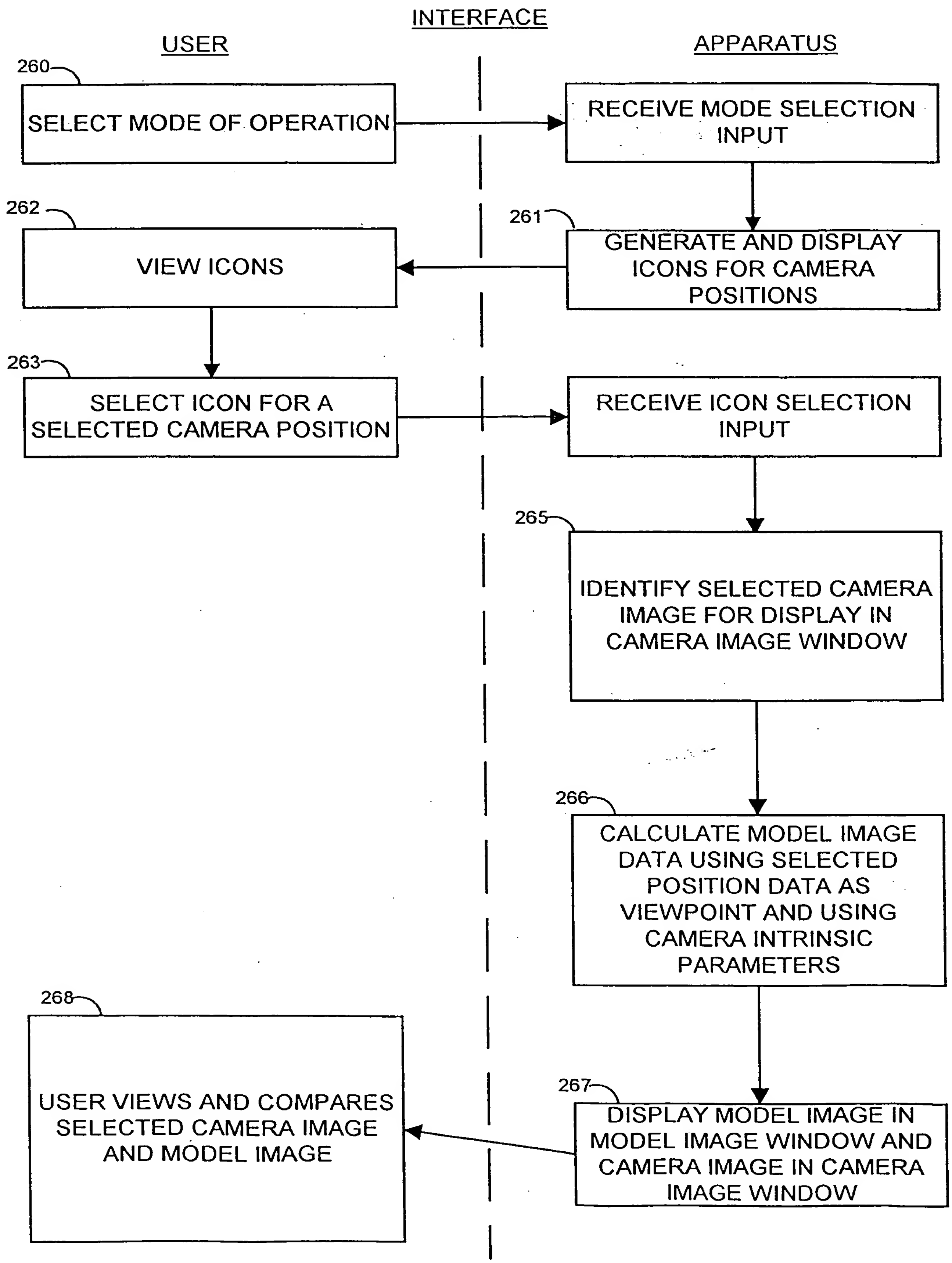
FIG. 26


INTERFACE
USER
APPARATUS
260
SELECT MODE OF OPERATION
RECEIVE MODE SELECTION INPUT
262
VIEW ICONS
261
GENERATE AND DISPLAY ICONS FOR CAMERA POSITIONS
263
SELECT ICON FOR A SELECTED CAMERA POSITION
RECEIVE ICON SELECTION INPUT
265
IDENTIFY SELECTED CAMERA IMAGE FOR DISPLAY IN CAMERA IMAGE WINDOW
266
CALCULATE MODEL IMAGE DATA USING SELECTED POSITION DATA AS VIEWPOINT AND USING CAMERA INTRINSIC PARAMETERS
268
USER VIEWS AND COMPARES SELECTED CAMERA IMAGE AND MODEL IMAGE
267
DISPLAY MODEL IMAGE IN MODEL IMAGE WINDOW AND CAMERA IMAGE IN CAMERA IMAGE WINDOW

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